SOME FACTORS WHICH INFLUENCE THE PROTEIN CONTENT OF MONTANA WHEAT

by

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INTRODUCTION

Importance of Protein in Wheat

For many years, the protein content of the grain of the common bread wheats has been recognized as a reasonably reliable index to the value or quality of those wheats for the manufacture of flour. The past decade has witnessed some rather striking changes in the production of bread in the United States with the result that the protein test has increased in importance as a means of evaluating wheat for baking purposes. Where once the housewife did most of the baking for her family, it is estimated (76)* that the commercial bakeries now produce 40 per cent of the bread consumed in American homes. With this large transfer of bread-making from the home to the bakeshop, new problems have developed. Competition forces the commercial bakeries to speed up their production methods in order to reduce costs per unit to a minimum. Large mechanical mixers are used, handling several hundred pounds of dough at one time. Mechanical mixing at high speeds requires a strong flour made from wheat that contains a high percentage of protein

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*Reference is made by number in parenthesis to "Literature Cited" page 144.

of good quality. Furthermore, a strong flour made from high quality protein wheat has a larger capacity to absorb water, with the result that more loaves of bread are obtained from every one hundred pounds of flour. In addition, a better quality of bread is produced.

Aside from its importance in the making of bread, there are other reasons for the emphasis which the protein content of wheat is receiving. The percentage of protein in any lot of wheat may be determined quickly and accurately, hence it probably is the best single index to use in estimating the value or quality of wheat as it arrives at the terminal markets.

Analyses have shown the extreme variability of the protein content of wheat. Wheats from different parts of the United States, from different counties within any one State, from different farms within any one county, from different fields on the same farm, and from different parts of the same field, have shown marked differences in protein content. Also there are variations due to varietal and seasonal differences, not to mention many other causes.

As the years advance, wheat growers may find it more difficult to produce high quality protein wheat, since there is evidence (18) of the fact that soil conditions are changing so as to make the production of such wheat less common.

The reasons for the prominence now accorded protein in wheat, serve also to emphasize the importance of studies designed to provide, if possible a better understanding of the factors which control the manufacture of protein in the wheat plant and its storage in the grain.

Montana Interested in High Quality Protein Wheat

Montana is an important wheat State, ranking second in the production of hard red spring wheat with an average annual crop (1925 to 1929 inclusive) in excess of 46 million bushels, and in addition, harvesting each year, approximately 9 million bushels of hard red winter wheat. Wheat is grown in this State under conditions which result in grain of high quality. The records of the Bureau of Agricultural Economics, United States Department of Agriculture, show that during the eight-year period (1920 to 1927 inclusive) nearly 70 per cent of the hard red spring wheat from Montana graded No. 1 at the terminal markets, evidence of superior quality as measured by test weight, dryness, purity and freedom from inseparable foreign material. Additional evidence of the high quality of Montana's hard red spring wheat is presented in Table I and Figure I which show that during the seven-year period (1923 to 1929 inclusive) 82.5 per cent of the car-load shipments received at Minneapolis

Table I: Carlot Shipments of Montana Hard Red Spring Wheat Received At Minneapolis Which Were Tested for Protein Content During 1923 to 1929, Grouped According to the Frequency of the Various Percentages of Protein

Protein Percentage Interval	Percentage of Cars in Various Protein Percentage Intervals 1923	1924	1925	1926	1927	1928	1929	Ave.
8.0							T	T
9.0	0.1	1.6	0.1	T	0.6	0.4	0.3	0.4
10.0	2.0	5.4	0.6	0.7	6.8	3.7	0.6	2.7
11.0	9.2	19.1	3.0	4.1	37.7	22.9	3.5	14.2
12.0	34.1	36.6	9.9	12.1	39.0	43.4	6.6	26.0
13.0	34.7	23.8	24.5	25.2	11.9	23.3	18.3	23.1
14.0	14.6	9.5	30.2	30.3	2.7	5.4	21.0	16.2
15.0	4.1	3.2	20.7	19.7	1.0	0.8	19.4	9.8
16.0	1.1	0.3	8.6	6.4	0.2	0.1	14.5	4.1
17.0	0.1	0.5	2.2	1.1	T	T	10.3	2.0
18.0			0.2	T			4.4	0.7
19.0			T	T			1.0	0.1
20.0							T	T
12% and above	88.7	73.9	96.3	94.8	54.8	73.0	95.6	82.5
No. of cars tested	1434	560	4466	5984	8161	11602	2500	

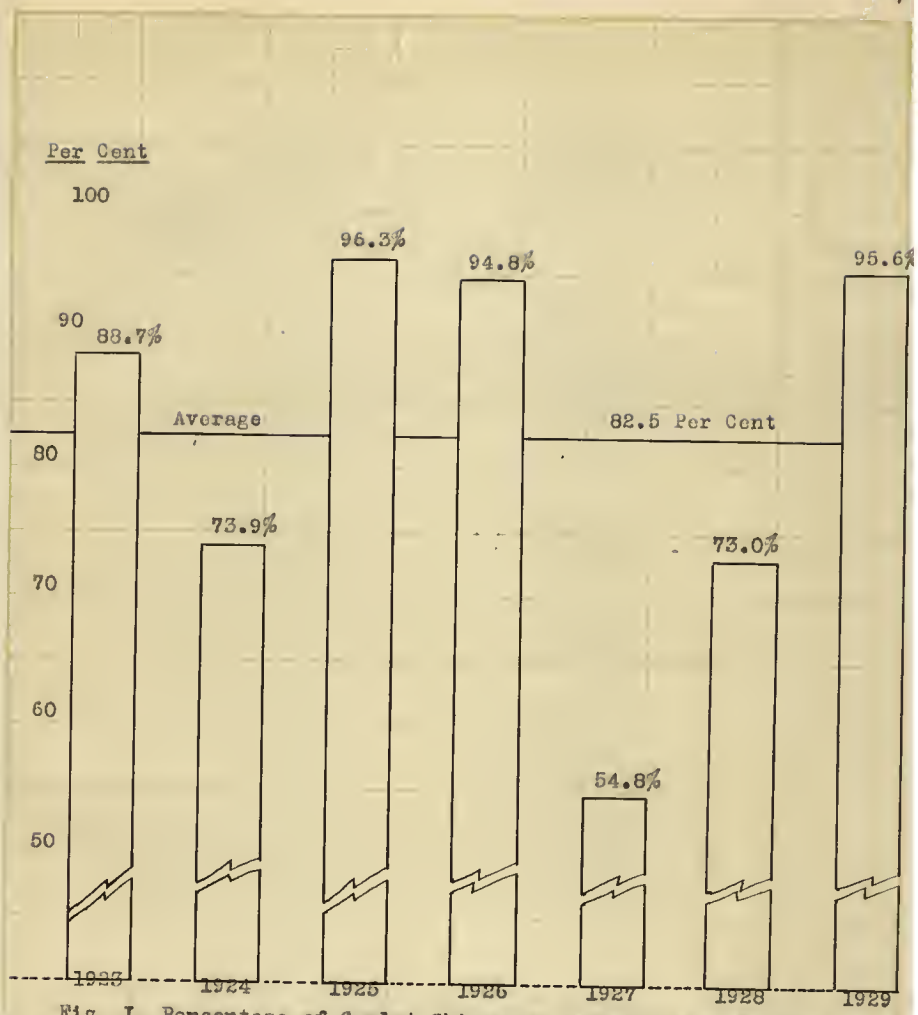

Fig. I. Percentage of Carlot Shipmente of Montana Grown Hard Red Spring Wheat Testing 12.00 Per Cent Protein or Over at Minneapolis, 1923 to 1929 Inclusive and Average

during the heavy marketing months 12.00 per cent protein or above.

While the State has certain natural advantages in the production of wheat, including soil and climatic conditions which favor high quality, and cheap lands adapted to the use of low-cost methods of production, Montana's wheat growers are seriously handicapped with an expensive haul to place their crop on the terminal markets. Eastern Montana points, shipping about 650 miles to Minneapolis are subject to a freight charge of approximately 18 cents per bushel, while shippers in central Montana with a haul of 950 to 1050 miles, pay from 24 to 26 cents per bushel for freight.

Since wheat of high quality, particularly that with a high protein content, often sells at a premium at the terminals, the wheat producers of Montana are much interested in practical methods of production which will return high yields of grain containing the maximum amount of protein in order that they may obtain the full advantage of the extra price, if any, when it is paid. In this connection, it may be of interest to review the data in Table II showing the average premiums paid per bushel for protein over the price paid for No. 1 Northern Spring (cash close) by months at Minneapolis from 1926 to 1930 inclusive (137). With the increasing demand for the class of wheat from which high grade flours are

Table II: Average Premiums Paid Per Bushel for Protein Over the Price Paid for No. 1 Northern Spring (cash close) by Months, Minneapolis, 1926 to 1929, inclusive. (World Wheat Prospects, U. S. D. A. Bureau Agricultural Economics, September 29, 1930)

Year	No. 1 Nor. Spg. Cash Close			Per Cent Protein								
				12 Per Cent			13 Per Cent			14 Per Cent		
	July Cents	Aug. Cents	Sept. Cents	July Cents	Aug. Cents	Sept. Cents	July Cents	Aug. Cents	Sept. Cents	July Cents	Aug. Cents	Sept. Cents
1926	168.3	150.9	140.8	5.5	4.0	3.3	8.1	7.1	6.6	10.4	9.4	9.1
1927	144.1	143.0	132.3	4.2	4.3	5.3	10.3	9.8	12.8	15.1	15.7	20.2
1928	132.8	112.3	110.9	8.9	6.6	6.3	22.8	16.8	15.9	32.9	24.8	25.3
1929	137.6	133.2	132.9	1.2	0.9	1.0	9.1	5.1	2.4	17.3	7.6	3.6
1930	89.1	89.2	--	2.8	1.1	--	5.3	1.8	--	7.3	2.6	--

produced and because of the keen competition among the buyers for large milling companies which must have wheat of the proper quality to meet the specific demands of their retail trade, there is justification for believing that the price paid for wheat at the terminal markets in the future will be influenced in part at least, by its value for the making of flour. At the same time, wheat growers must not lose sight of the fact that the size of the premium that is paid for extra protein will be governed very largely by the volume of high protein wheat that is available in any particular year. For example, in 1928, when there was a scarcity of high protein wheat in the hard red wheat producing sections of the United States, the premiums were unusually high. On the other hand, in 1929, when much of the hard red wheat of this country averaged high in protein content, the demand for this class of wheat was materially reduced, resulting in much smaller premiums. In fact, in high protein years, it is not unusual for mill buyers to pay a premium for wheat containing a low percentage of protein, to be used in mixing with stocks of wheat which show an extra high protein content.

REVIEW OF LITERATURE

In order to give a clearer understanding of the

problem treated in this paper, the review of literature has been divided into three sections, namely, (a) General historical sketch of the investigations dealing with variations in the protein content of wheat; (b) assimilation and elaboration of nitrogen by the plant at successive stages of growth; and (c) a summary of the investigations dealing with individual causes of variation in the protein content of wheat.

The writer had access to the Reference Library of the United States Department of Agriculture in preparing this review of literature and through this library certain references were obtained from the Library of Congress. Because of the large number of publications which deal with the protein content of wheat, no effort has been made to cite a complete list of the references reviewed on each individual phase of this paper but rather the writer has chosen to refer only to the work of investigators who have made important contributions to the knowledge of the particular subject under consideration. Under the heading "Literature Cited" is given a complete list of references cited by number in the manuscript.

General Historical Sketch Of Investigations Dealing With The Causes of Variation In the Protein Content of Wheat

The causes of the extreme variation in the protein content of wheat have been the subject of extensive investigation for years. Considering the wide range of conditions under which the research work on this problem has been conducted, it is not surprising to find some divergence of opinion as to the factors which are important in influencing the protein content of wheat.

In 1884, Lawes and Gilbert (55) called attention to the fact that "the better matured grains contain the lower percentages of nitrogen and total mineral matter and a higher percentage of starch" and that there was "a much greater range of variation" in the percentages of the various constituents in the plant, "due to variations of season, than to variations of manure". Later, they (56) mention that nitrogen in the wheat crop "declines to a marked degree"when grown on the same land continuously.

In 1900, Melikov (68) after making analyses of crops from 1885 to 1899, found the wheat of southern Russia "rich in nitrogenous substances, the proportion of the latter varying with the weather from 14.00 to 21.20 per cent".

In 1901, Wiley (129) in summarizing the results of some of his work stated that the wide variations in protein

content were not due to soil, fertilizers, or cultural methods, but were influenced almost entirely by the "metsorological conditions". Zavitz (133) of Canada mentions that wheat is very susceptible to changes according to its environment, including "season, soil and manure, locality and seed". Lyon (60) in 1905 called attention to the fact that among other things, the percentage of protein in wheat was influenced by the stage of development of the kernel. LeClerc (57) in 1906 and again (58) in 1910 presented a rather complete statement of the factors known to influence the protein content of wheats. These include (a) climatic or seasonal conditions such as precipitation, temperature, sunshine, and humidity; (b) soil; (c) fertilizers; (d) tillage; (e) previous crop; (f) seed; (g) length of period from heading to ripening; (h) time of planting; (i) time of harvest and (j) irrigation. Numerous investigators including Brenchley and Hall (11) and Thatcher (114) have called attention to the fact that varieties of wheat grown under identical conditions will vary as to the percentage of protein in the grain.

Within more recent years, those who have studied the factors influencing the protein content of wheat have assisted somewhat in clearing up certain points concerning which there has been more or less controversy. Swanson

(110) outlines the present situation rather concisely when he states that "both practical experience and experimental evidence have shown that the protein content of wheat is influenced by several factors which are at the same time interacting, and conclusions cannot be drawn from the action of any one factor without at the same time considering other related factors". Among the factors which are emphasized by Swanson and his associates at the Kansas Station are climate, date and rapidity of ripening, variety, irrigation and amount of available nitrogen.

Assimilation And Elaboration Of Nitrogen By The Wheat Plant At Successive Stages Of Growth

A study of the factors which influence the protein content of wheat necessitates at least a working knowledge of the assimilation and elaboration of nitrogen by the plant at successive stages of growth or development. The investigator must know the source of the nitrogen, when the largest amounts are available, and in what forms it is used by the plant. He also must have information as to the period of development of the plant during which the use of nitrogen is greatest and when and in what tissues nitrogen is stored.

It is a generally accepted fact that all of the nitrogen used by the wheat plant is obtained from the soil, and

that the plants can take up or absorb only nitrogen which is in a readily available or soluble form. Available nitrogen is the product of bacterial action. Since bacterial action is influenced materially by certain factors (80) including the amount of organic matter and moisture in the soil, along with proper aeration and suitable temperatures, it is apparent that the amount of available nitrogen in any soil may vary considerably depending on the soil and the season. One year with another available nitrogen is accumulated in the soil most rapidly when moisture and temperature conditions are favorable. Whiting and Schoonover (122) of Illinois report that nitrate production is most active in late spring and early summer because of optimum moisture and temperature conditions and that on land cropped to wheat the largest nitrate accumulation is in May. These investigators also found that the greatest use of nitrates by the wheat crop occurs in a period from the middle of May to early June.

Kedzie of Michigan and Teller of Arkansas made distinct contribution to the information dealing with the composition of the wheat plant at successive stages of development. The results of Kedzie's work (43) were published in 1893. Beginning when "the wheat was headed out and was in blossom

but the berry was still very immature" samples of Clawson wheat were harvested at two o'clock P. M. daily on forty-six consecutive days. Because of the importance of Dr. Kedzie's work and its influence in stimulating further research on this problem, Figure 2 has been prepared to show graphically the changes in the percentages of protein and carbohydrates as maturity advanced by two-day intervals. The data from which this graph was constructed are contained in Table III. It will be noted that the percentage of protein decreases as that of carbohydrates increases. From the eighteenth day, until the grain is ripe, there are no marked changes in the percentage of either constituent.

Teller (111) harvested wheat at the same hour on each of forty-one successive days beginning when the wheat was "just past blossoming and the grain was set". Chemical analyses showed results quite similar to those obtained earlier by Kedzie, with the exception that the percentage of protein in the kernel reached its lowest point about one week before ripening and after that showed a slight increase.

In 1893, Snyder (95) published the results of his analyses of wheat grown in Minnesota in 1892 and 1893. The samples were harvested at four stages of maturity, namely, (a) 50 days after seeding - plants 18 inches high; (b) 65

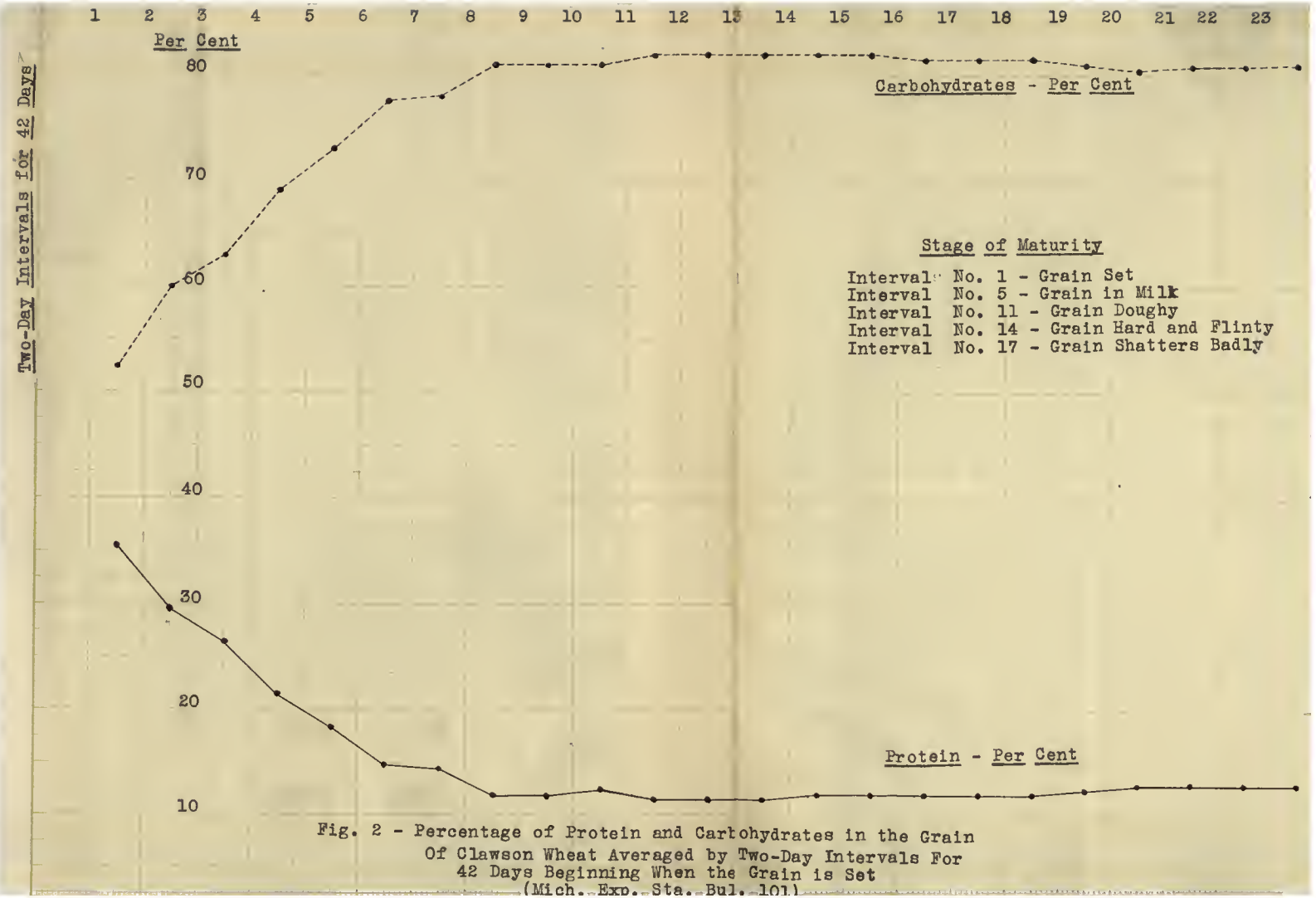
Two-Day Intervals for 42 Days
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Per Cent
80
70
60
50
40
30
20
10
Carbohydrates - Per Cent
Protein - Per Cent
Stage of Maturity
Interval No. 1 - Grain Set
Interval No. 5 - Grain in Milk
Interval No. 11 - Grain Doughy
Interval No. 14 - Grain Hard and Flinty
Interval No. 17 - Grain Shatters Badly

Fig. 2 - Percentage of Protein and Carbohydrates in the Grain Of Clawson Wheat Averaged by Two-Day Intervals For 42 Days Beginning When the Grain is Set (Mich. Exp. Sta. Bul. 101)

Table III - Percentage of Protein and Carbohydrates In the Grain of Clawson Wheat, Averaged by Two-Day Intervals Over a Period Of 42 Days Beginning When Grain is Set. (Mich. Exp. Sta. Bul. 101)

Interval No.	Remarks	Percentage of Protein	Percentage of Carbohydrates
1	Grain Set	35.55%	52.42%
2		29.46%	59.89%
3		26.75%	63.22%
4		21.34%	69.13%
5	Grain in milk	18.41%	73.14%
6		14.86%	77.52%
7		14.54%	78.26%
8		12.19%	80.81%
9		12.21%	81.13%
10		12.66%	80.72%
11	Grain doughy	11.78%	81.77%
12		11.75%	81.96%
13		11.74%	82.02%
14	Grain getting hard	11.82%	81.92%
15	and flinty	11.86%	81.84%
16		12.37%	81.55%
17	Grain shatters badly	12.10%	81.62%
18		12.19%	81.70%
19		12.52%	81.25%
20		13.18%	80.64%
21		12.90%	80.80%
22		12.83%	80.90%
23		12.87%	80.85%

days after seeding, crop fully headed; (c) 81 days after seeding - grain in the milk; and (d) 105 days after seeding approximately 20 days prior to harvest. Snyder concluded that the wheat plant takes up over three-fourths of its food from the soil before heading out and that the nitrogen

"is assimilated by the plant more rapidly than the mineral matters taken as a whole". He found that the plants had taken up 86 per cent of their total nitrogen by the end of the first 50 days.

Lyon and Kezer (61) found that "there is a steady increase in the amount of yellow-berry as the grain becomes riper". Lyon (60) states that these results agree with those of several German investigators, including Heinrich who shows that the percentage of nitrogen in the wheat kernel decreases during the ripening process, while that of the carbohydrates increases.

LeClerc (57) reports that "up to the time of full flowering, wheat has elaborated 87 per cent of the dry matter and has absorbed all of the nitrogen, lime and potash that it requires and 74 per cent of the phosphoric acid". He agrees with Deherain and Dupont (22) and Adorjan (1) that during the latter part of the life of the wheat plant, there is but little new food manufactured and that the principal function of the plant is to transport the elaborated materials to the head and grain.

The studies of Brenchley and Hall (11) in England show that the percentage of nitrogen in the dry matter of the grain decreases rapidly at first but within 18 days after first bloom becomes fairly constant with indications

of a slight rise toward the close of the experiment which ended 39 days after first blossoming. These investigators argue that plants do not cease to draw "nutriment from the soil at an early date", but rather that as long as any part of the plant remains green, uniform material is moved into the kernel, "possessing always the same ratio of nitrogenous to non-nitrogenous materials and ash".

In general, the work of Thatcher, (118) and Kiesselbach (45) agrees with that of Teller, with perhaps slightly more emphasis on the tendency for the percentage of protein to increase as maturity advances past the milk stage. These latter studies seem to strengthen the results of work done by Harper and Peter (29) of Kentucky in 1904, who found "more protein" in wheat cut when fully ripe than in that harvested while in the milk or dough stage. Benton (8) and Swanson, Fitz and Dunton (109) report little or no change in the protein content of wheat after the crop has become fully ripe.

In 1910, Moertlbauer (70) found evidence of the fact that the time at which nitrates were made available to the crop influenced the physical and possibly the chemical characteristics of the grain. In more recent years, this phase of the problem has been followed up by other investigators.

Garickes (26) experiments seemed to justify the conclusion that "variations in the protein content of the grain are not always due to unknown genetic factors but they may be definite non-inheritable responses of the plant to certain conditions of its external environment". He applied sodium nitrate to wheat at planting time and at 17, 33, 48, 72 and 110 days after planting and found marked increases in the percentage of protein in the grain as maturity advanced.

Neidig and Snyder (72) determined that when the wheat crop received "cumulative additions of sodium nitrate thruout the season" both the protein content and yield were increased over that obtained when the same amount of fertilizer was added at the time of planting.

In 1924, Neidig and Snyder (73) reported on experiments in which sodium nitrate was applied to wheat at different stages of growth in soil that contained varying amounts of moisture. Their conclusions are quoted below: (a) "High moisture in soil containing sufficient available nitrogen for maximum growth and development of the wheat plant results in high yielding wheat containing high protein content". (b) "Low moisture in soil containing an excess of available nitrogen will produce lower yields but higher protein". (c) "High or optimum moisture in soil which has considerable nitrogen available in early stages but an

insufficient amount during fruiting and and ripening period for maximum growth results in high yield of wheat but low protein content". (d) "Under field conditions high moisture content as somotimes occur in seasons of abundant rainfall properly distributed in the growing period on average soil will produce high yield with low protein. A very rich soil under the same conditions will produce high yields but may show an increase in protein if there is sufficient available nitrogen during the entire life of the plant."

In 1927, Gericke (27) reported on a most interesting exporimont in which 9 varieties of wheat were fertilized at three stages of growth, (a) planting time; (b) 30 days after planting; (c) 90 days after planting, checking against no fertilizer. He found that varieties react differently to the different fertilizer treatments. In explaining these varietal differences he assumes that "the percentage of nitrogen or any other constituent in plant tissue is obviously a factorial measurement of the quantity of that element the plant has made as the result and in part as an incidence of absorbing that quantity of the element. That the measure of growth plants make from any given quantity of nitrogen absorbed may vary markedly is only another way of stating that wheat varies in the percentage of this constituent. Gericke then states that an explanation of the variations in

the protein content of grain requires consideration of "the factors which determine the mass of grain material that will be produced and into which a given quantity of nitrogen will be distributed and assimilated as protein."

Pointing to the fact that in the wheat plant, nitrogen is used in both grain tissues and non-grain tissues and that since the quantity of one bears a certain relation to that of the other, any factor that influences "the apportionment of nitrogen to these two classes of tissues conceivably must be important in determining the causes of variation in responses" from applications of nitrate fertilizers.

He observed that two factors greatly influenced the development of vegetative or non-grain tissue, namely, tillering, and a long growing period. If as is often true, the amount of available nitrogen in the soil is "less than the plants can absorb and utilize", excessive vegetative growth in the earlier stages, will greatly reduce the amount of nitrogen available for grain, since "some of the nitrogen required for vegetative growth cannot be utilized later for protein in the grain". Two conclusions from Gericke's work seem rather pertinent: (a) "The supply of nitrogen available for the quantity of grain that any state of vegetative development may induce determines the protein content of any sample of wheat". (b) "The amount of nitrogen available at

different stages of growth affect the protein content of grain".

After reviewing the work of the investigators who have given rather detailed attention to the percentage composition of the wheat plant at successive stages of development, the bulk of the evidence seems to show that under average field conditions the percentage of protein in the wheat kernel decreases gradually as maturity advances up to the "milk" or "early dough" stages, beyond which a slight increase may occur up to the time the grain is fully ripe. During this same period there is a marked increase in the percentage of carbohydrates in the grain. Recent experiments also prove rather definitely that the amount of nitrates available to the plant as well as the period of growth during which they are available have a marked influence on the percentage of protein. It seems quite obvious that any condition which interfers with normal development and maturity of the wheat crop might appreciably influence the percentage of important constituents such as protein and carbohydrates.

Investigations Dealing With The Causes Of Variation In The Protein Content Of Wheat

In summarizing the information obtained in reviewing the literature dealing with the causes of variations in the

protein content of wheat, no attempt has been made to treat the various factors in the order of their importance. However, the evidence made available by the various investigators will doubtless enable the reader to form rather definite ideas as to the importance of the different factors in affecting protein content.

Environment or Locality. Environment has been defined by LeClerc (58) as including all factors of any locality which might tend to influence the growth of plants, and refers specifically to climatic conditions, soil, time of planting and harvesting, methods of seed bed preparation and fertilizing, crop sequence and thickness of seeding. It is perfectly clear; therefore, that environment is composed of several interrelated factors and is capable of influencing the yield and composition of the wheat crop of any season in innumerable ways.

Wiley (127) was among the first of the American investigators to publish data bearing on the protein content of wheat grown under different environments. In 1884, he published the results of over 400 analyses grouped by districts, showing a range in protein content of from 9.73 per cent in the Pacific States to 12.74 per cent in the Western States. Carleton (20) recognized the influence of environment when he compared the climatic and soil conditions of

the best hard red spring wheat sections of the United States and Russia. The effect of environment upon the yield and composition of wheat has been noted in crops from different states, from different counties within any one state, from different farms within any one county, and in fact, from different fields in the same farm. Thatcher (116) during a period of five years (1905 to 1909) noted variations in protein of 9.03 to 12.82 per cent from different localities in Washington. Ladd (52) in studying hard spring wheat from ten localities of North Dakota in 1911 found a variation in protein of from 14.50 to 18.56 per cent. Bailey (5) made protein analyses of Minn. 169 - Bluestem, a pure line selection, grown in eleven different places in Minnesota and found averages ranging from 11.17 to 16.02 per cent. Mangels Stoa and Dynes (66) noted a variation in the average protein content of the 1928 crop of hard red spring wheat from 48 counties in North Dakota ranging from 10.75 to 13.42 per cent. Call, Green and Swanson (18) report that over a period of seven years, the average protein content of wheat from the various Kansas counties varied from 11.00 to 13.80 per cent, but add that no county or group of counties were always at the top or at the bottom in protein content. In 1928, Call (19) reported that four varieties of hard winter

wheat grown at Manhattan, Kansas in 1927 averaged 12.50 per cent protein while the same varieties grown at Hays the same year averaged 16.3 per cent, thus emphasizing again the influence of environment or locality. LeClerc (59) shows the effect of environment on protein content in his report on the triangular experiments conducted at stations in California, Kansas and Maryland. Seed from each of the three states when grown in California during a period of four years produced wheat which averaged 13.11 per cent. When grown in Kansas, the average was 18.83 per cent and in Maryland, 12.43 per cent. Examination of the data show two rather striking points: (a) Seed of any one variety obtained from different sources and differing widely in both physical and chemical characteristics, when grown in one locality under identical conditions will vary but little, if any, in composition. (b) Seed of any one variety from any one source when planted in different localities will produce crops which are quite different in physical and chemical properties. Environment, including both climatic and soil factors must be regarded as one of the major influences in causing variations in the protein content of wheat.

Climate. Climate has been defined by LeClerc (58) as

including rain, sunshine, humidity, temperature, winds and elevation. Add to this the infinite number of variations or changes that occur in each as the growing season advances and one can readily realize that "climate" in its relation to protein content of wheat is a most difficult problem to analyze. Furthermore, it is difficult to compare the climate of one locality with that of another because of the introduction of an additional complicated variable, namely, the soil.

Wiley (128) differed with his co-worker, Richardson (77) by placing greater emphasis on the influence of climate upon the protein content of wheat than on that of the soil. Soule and Vanatter (100) state that in Tennessee, climate seems to have more to do with producing high protein wheat than any other influence. Lyon (60) considers climate as a "potent factor" in determining the yield and quality of the wheat crop and adds that "effect of climate" is produced either by lengthening or shortening the growing season, particularly that portion of it during which the kernel is developing. Thatcher (114) found "wide variations in the chemical compositions of any given variety due apparently to the climatic conditions" and later (112) concludes that "any differences whether between varieties or between different samples of the same variety are due chiefly if not wholly,

to differences in the rapidity of ripening of the grain, or that any climatic condition which shortens the time between blossoming and full maturity will produce grain with a higher percentage of protein". LeClerc (58) reports that seed wheat of any one variety, from any one source when planted in different localities under different climatic conditions will yield crops which differ widely in appearance and chemical composition and that these differences are due "for the most part to climatic conditions prevailing at the time of growth". He further states that seed and soil are relatively unimportant in influencing the composition of crops. Shaw and Walters (90) and later LeClerc and Yoder (59) in discussing certain triangular experiments, state very definitely that climate is the principal factor in influencing the protein content of wheat. In this they are supported by Ladd and Stockham (53) who state that "there is no greater factor influencing the quality of wheat than the climatic conditions under which it is grown". Call, Groen and Swanson (18) think that climate has so much influence on the composition of wheat that it is "almost impossible in some localities to produce wheat of high quality". Swanson (110) maintains that the importance of climate is due to the fact that it is "the greatest factor influencing

the soil solution".

In spite of the evidence emphasizing the importance of climate in relation to protein content of wheat, there are investigators whose findings seem to support somewhat different views. Because of the fact that they found such marked variations in the protein content among individual plants in each of three varieties of California wheat grown under the same conditions of soil and climate, Shaw and Gaumnitz (89) are inclined to doubt the importance of climate and soil in influencing chemical composition and seek the "ultimate causes of difference within the plant itself".Dr. Headden (33) (36) believes that under Colorado conditions the soil should be given far more emphasis than climate in connection with quality in wheat.

Since climate is a factor composed of several interrelated factors it cannot be easily interpreted. However, in the light of the information now available it appears that Swanson (110) has described climate most accurately as it relates to high or low protein content. A climate characterized by "dry winters, cool springs with moderate rainfall and hot, fairly dry summers usually produces a hard, strong wheat" with a high percentage of protein. A climate with "more open winters, a high rainfall in spring and summer produces a soft wheat or one characterized by yellow

berries and a relatively high starch content". He further calls attention to the fact that "as weather or climatic conditions vary from year to year", wheat which varies considerably in quality may be produced in different years in the same locality.

Season. As early as 1884, Lawes and Gilbert (55) noted the distinct influence of the season for they call attention to the fact that "variations of seasons" produced greater changes in the composition of the wheat grain and straw than "variations in manure". Molikov (68) after studying the wheat crops of Russia from 1885 to 1899 found that the seasonal variations in protein content ranged from 14.00 to 21.20 per cent, being highest in dry years and lowest in years of good crops. Wiley (129) in 1901, explained that the wide variations in the composition of wheat "was not due to the character of the soil, nor yet to the character of the fertilizer employed, nor in the method of culture, but depended almost entirely upon the meteorological conditions". Dehorain and Dupont (22) emphasized the influence of season upon the chemical composition of the wheat grain. In 1888, with a slow ripening process and late harvest, the percentage of gluten was 12.60 and that of starch, 77.2, while in 1889, with a hot summer hastening the maturity

the grain contained 15.30 per cent of gluten and only 61.9 per cent of starch.

A large number of the station workers in the United States have presented data to show the importance of the season in changing the composition of wheat with particular emphasis upon the protein content of the grain. Among these should be mentioned Williams (131) Snyder (96) Jones and Colver (41) Call, Green and Swanson (18) Kezer (44), Schollenberger and Clark (84) and Mangels, et al (64 and 66). Schollenberger and Clark illustrate the seasonal variation within a variety by using data for Marquis spring wheat grown at twelve experiment stations in western states during five crop years, 1917 to 1921, inclusive. A study of their data reveals the facts (a) that at any one locality the variations due to seasonal influence are greater than those due to variety, and (b) that the variations in protein content due to locality are far more important than those caused by seasonal differences.

Ladd and Bailey (49) found that the range of protein in wheat grown on the same farm in North Dakota in different years has frequently amounted to 4.00 and 5.00 per cent and occasionally has differed as much as 6.0 per cent.

Ames (2) of Ohio and Swanson (110) of Kansas Maintain

that variations due to the seasonal influence are greater than those due to differences in the soil and Kiesselbach (45) of Nebraska agrees with Schollenberger and Clark (84) that the variations due to season are greater than those between varieties.

The work of Soule and Vanatter (100), Shepard (92), Lyon and Kezer (61), Shaw (88), Roberts and Freeman (78), Call and Salmon (16) and Call(19), also Salmon and Throckmorton (81) would seem to support a summary statement on the influence of season as follows: The protein content of wheat may vary to a marked extent from one season to another and that in general, seasons which are hot and dry causing the crop to ripen rapidly produce wheat with a high protein content while seasons with cooler temperatures and more moisture, particularly during the growing season are likely to result in wheat with a lower percentage of protein.

Rainfall. LeClerc (57) noted the effects of varying amounts of moisture on the composition of wheat when in 1903 and 1904 he compared samples grown on dry land with those grown in humid and irrigated localities. The dry land grown wheat contained approximately 3.00 per cent more protein then that grown under more moist conditions. However, he stresses the fact that rainfall and

temperature are closely related. Thatcher (116) reports "a very definite relation between the total rainfall and the composition of wheat grown in the different parts of Washington". Bailey (5) after studying rainfall data in Minnesota decided that "there is a relationship between the rainfall from April 1 to September 1 and the protein content". The protein decreased gradually as the rainfall for the period mentioned increased. Stockham (108) found that the composition of wheat is influenced somewhat by the soil but the effect of moisture is much greater. Ladd and Stockham (54) present data covering a period of years showing that the "protein content varies inversely as the soil moisture at maturity". Stewart and Hirst (106) in Utah found a "close relation" between the rainfall during the growing season and the protein content of wheat. An examination of their data seem to show that the rainfall for July is more closely related to protein content than is that for the months of April, May and June.

Sewell and Swanson (87) discovered no correlation between rainfall and the protein content of Kansas wheat. Neidig and Snyder (72) believe that if there is a sufficient supply of nitrogen available in the soil, "moisture is the chief climatic factor", influencing the yield and protein content of wheat.

Temperature. Williams (131) after four years work with 43 varieties of wheat in Ohio, found that protein content of winter wheat varied inversely as the mean temperature for June. Mangels (63) states that temperatures above normal for June and July increases the protein content of wheat, but unfortunately the climatic conditions which result in high protein are not favorable for high yields.

The evidence available does not make a clear case for either temperature or rainfall when considered separately which suggests the importance of the finding of LeClerc, namely, that "moisture and temperature are interrelated". This is further emphasized by Call, Green and Swanson (18) in pointing out the influence of rainfall and temperature. They cite the season of 1917-18 which was dry and warm, and produced wheat with a high protein content, while the next year was wet and cool and the protein averaged considerably lower.

Irrigation. Considerable prejudice has developed against wheat produced on irrigated land because it is supposedly softer and contains a lower percentage of protein than that grown on non-irrigated land.

Headden (32) (33) (35) seems firmly convinced that under Colorado conditions irrigation does not reduce the

protein content. On the other hand Shutt (93) of Canada and investigators in Utah (104) (125) (126) (105) (30) conclude with equal confidence that wheat grown under irrigation contains less protein on the average than that produced without irrigation. Knight (47) and Jones and Colver (40) (41) and Jones, Colver and Fishburn (42) found that excessive irrigation reduces the protein content but that it does not necessarily follow that all irrigated wheat is low in protein which suggests the possibility of the influence of the soil in the various localities. Knight produced Marquis spring wheat for a period of five years at the Nevada Agricultural Experiment Station without noting any decrease in quality when receiving less than 30 inches of water, with 7 inches or less at each application. Jones and Colver stress the fact that while irrigated wheat contains less protein than that non-irrigated, the difference is not great enough to support "the commonly held views regarding the relative values for bread making purposes of dry farmed and irrigated wheats". Their results indicate also that hard red spring wheats of the "highest quality" may be produced on irrigated land in southern Idaho "if other conditions for growth are favorable". These findings agree with those of Howard and others (37) of India, who state that irrigation and high protein content may go together "when

cultivetion is suitable and the amount of irrigation water regulated".

Soils. A review of the literature dealing with the soil and its relation to the protein content of wheat reveals considerable difference of opinion. Richardson (77) after having analyzed a large number of wheats from various parts of the United States was strongly of the opinion that the fertility of the soil greatly influenced the protein content. He supported his conclusions by citing as evidence the low protein content of wheat grown in the Atlantic States "where soils have become more or less worn out" as compared with wheat from the western states where "the soil contains those stores of plant food and nitrogen especially, which make a rich grain of wheat". He does not appear, however, to have satisfactorily explained the low protein content of wheat from the Pacific Coast states. Lawes and Gilbert (56) in summarizing their work on the Rothamsted station call attention to the fact that when crops are grown continuously on the same land without the addition of nitrogenous manures, both the yield and "the amount of nitrogen in the crop decline in a very marked degree". Other investigators who are inclined to attach some importance to the soil as a factor in influencing the protein content of wheat include Jones, Fishburn and Colver (39), Fraps (24)

Ames and Boltz (3), Headden (34), Neidig and Snyder (72) and Mangels (63). Stockham (108) states that in North Dakota the soil nitrogen decreases as one goes westward in the state and the tendency is for the wheat to correspondingly increase. Dr. Wiley (129) did not agree with his associate, Richardson, maintaining that "the soil, as a rule, has the least effect of all the important factors of environment upon chemical composition, provided, of course, that it contains the essential elements of plant food necessary to produce a crop". Soule and Vanatter (100) report from their work in Tennessee, that a rich soil or the use of large quantities of commercial fertilizers "does not seem to increase the protein to any appreciable extent".

Perhaps the best evidence to show the relative unimportance of soil in effecting changes in the protein content of wheat is that resulting from the triangular experiments conducted over a four year period in California, Kansas and Maryland. This experiment involved the use of "a fairly good wheat soil", one from each state put down side by side in each of the three localities and planted to the same variety of wheat. Shaw and Walters (90) and LeClerc and Yoder (59) have analyzed the results of this and other triangular experiments and conclude that soil plays

a relatively small part in influencing the nitrogen content of the wheat crop. Thatcher (117) offers evidence from his work in Washington which confirms the results of the triangular experiments. It appears therefore, that while the soil may influence the protein content of the wheat crop to a certain extent, its influence is exceeded by that of other factors.

The differences of opinion regarding the importance of the soil as a factor in influencing the protein content of wheat may be explained in part at least by the fact that several interrelated factors are involved, and that there is a possibility of the effects of these being masked or overshadowed entirely by variations in protein content caused by differences in seasonal conditions. It will be of interest to study the effect of factors closely related to the soil, including the use of fertilizers, irrigation, tillage methods and crop sequence.

Fertilizers. Considerable investigational work has been done with commercial fertilizers and manures in an effort to improve the composition and baking value of wheat. Because of the importance of the nitrogenous material in the wheat kernel, most investigators have undertaken to improve wheat by increasing its nitrogen content. For various reasons, the experiments with fertilizers have not produced

uniform results, although some rather definite conclusions are possible.

Menke (69) grew eleven varieties of wheat in Arkansas, both with and without commercial fertilizers. Although no mention is made of protein content it is of interest to note that the fertilized wheats received higher grades on the St. Louis market. After working with commercial fertilizers over a period of five years, Williams (131) of Ohio found that plots receiving no fertilizer or those without phosphorus produced low yields of grain with a light test weight but a high percentage of protein. When phosphorus fertilizers were used the yields were greatly increased and the grains were larger and plumper, with a high starch content and low in protein. LeClerc (57) mentions that soils and fertilizers have more or less influence on the quality of wheat, but that this influence is "much less marked" than is that of "rainfall or of climate in general". Snyder (99) from work in Minnesota found that in all tests with one exception, the largest protein content was obtained from wheat grown on plots to which either nitrogen alone or a complete fertilizer which included nitrogen was applied. In 1917, Ames and Boltz (3) published information concerning the fertilizer experiments with

wheat in Ohio. By adding phosphorus without nitrogen to soils which respond more readily to the first than to the latter, the yield was increased but the percentage of protein was materially decreased. When nitrogen was added with phosphorus, both the yield and protein content of wheat were increased. These investigators also found that the highest protein was obtained in wheat grown on soils deficient in available phosphorus, but well supplied with nitrogen in available form. Headden (32) (33) (35) (36) believes that the composition of wheat is "much more easily influenced" by the fertility of the soil than "we have been taught to believe". His investigations point rather definitely to three conclusions as follows: (a) Nitrogen in the form of nitric nitrogen in the soil increases the nitrogen content of the wheat grain; (b) phosphorus shows a tendancy to depress the amount of nitrogen in the grain; (c) potassium caused a marked depression in the nitrogen content of the grain. Neidig and Snyder (72) (74) obtained only a slight increase in the protein content of wheat in Idaho by applying manure at the rate of 20 tons per acre every third year but when certain nitrogen fertilizers such as sodium nitrate and ammonium sulfate were used, there was a marked increase in the percentage of protein over that grown without fertilizer. Briggs and Hawkins (12) in

Arizona obtained increased yields accompanied by increased protein content from using a nitrogen fertilizer on a soil which did not respond to either phosphorus or potash.

It is apparent that so far as protein content alone is concerned, improvement may be obtained by using fertilizers which will supply nitrogen in a readily available form. It is also evident that the balance or ratio between available nitrogen and available forms of phosphorus and potassium has considerable effect on the protein content of the wheat crop.

Available Nitrates. The literature dealing with the factors which determine the protein content of wheat and other crops places considerable emphasis on the part which available nitrogen plays in the proper growth and development of the crop. In 1905, Lyon and Kezer (61) concluded that "the amount of readily available nitrogen in the soil especially during the period of growth previous to heading" along with varietal tendencies and climatic factors were the conditions which influence "the percentage of nitrogen that the kernels contain". Swanson (110) states that the production of high protein wheat is possible only if there is in the soil an adequate supply of available nitrogen. Burke (14) concludes from his data that "nitrate nitrogen is certainly a factor and probably the greatest factor in

controlling the yields and quality of wheat in Montana".

Since much of the nitrogen in the soil is not readily available to growing plants, it is conceivable that tillage and cropping practices known to influence the availability of nitrogen would also effect the protein content of wheat.

Length of Fruiting Period. Several investigators have found that the length of the period from heading until full maturity usually designated as the "fruiting period", has a marked influence upon the percentage of protein in the grain of wheat. Deherain and Dupont (22) noted that in 1888, with a late harvest and the wheat ripening slowly, the grain contained 12.60 per cent of protein and 77.2 per cent of starch. In 1889, the summer was hot, ripening the crop rapidly with the result that the grain analyzed 15.30 per cent protein and only 61.9 per cent of starch. In 1901, Schribaux (85) pointed to the fact that "all circumstances tending to shorten the period of growth favor the formation of nitrogenous substances in the grain." An identical conclusion was reached by Wiley (129) at the same time. In 1908, Roberts and Freeman (78) noticed a similar influence of the length of the fruiting period as applied to yellow berry content of wheat.

The general statement that a long fruiting period produces wheat lower in protein content and higher in percentage

of carbohydrates while in a short fruiting period, the situation is reversed, is supported also by the work of Blanchard (9), Thatcher (113), (117), LeClerc (57) and Swaneon (110).

Unpublished data (136) from the University of Alberta, Edmonton, Alberta resulting from a variety and strain of spring wheat shows that in 1929 ten varieties and strains whose "growth period ranged from 102 to 104 days - average of 103 days, contained a protein content which ranged from 14.4 to 16.6 per cent - average of 15.3 per cent. Fifteen whose growing period was 98 days or less averaged 97 days (95 to 98) contained an average of 16.6 per cent protein."

Class Of Wheat. Considerable evidence has been obtained regarding the average percentage of protein contained in each of the various classes of wheat. Thomas (120) summarized the data on several hundred analyses made during the six years 1908 to 1913. These analyses, grouped by classes are as follows: (a) Durum - 154 samples averaged 14.30 per cent protein, (b) hard red spring - 546 samples averaged 12.90 per cent, (c) hard red winter - 359 samples averaged 12.10 per cent and (d) soft red winter - 235 samples averaged 10.60 per cent protein.

Data published by Schollenberger and Clark (84) in 1924, covering analyses made during a period of seven years, 1915

to 1921, rank the classes in the same order, but the averages in each case are slightly higher. Thatcher (112), Stewart and Greavee (104), Ladd (50), (51) Bailey (5), (7), Thomas (119), Stephens and Hyslop (102), Kiesselbach (45), Schafer (82) and Kezer (44) have called attention to the fact that hard red spring wheat materially exceeds hard red winter wheat in the average percentage of protein in the grain. Thatcher (117) and Olson (75) have found that in Washington, varieties which may be sown either in the fall or in the spring, average noticeably higher in protein content from spring sowing. Thatcher attributes this difference in composition of fall and spring sown grain to the length of the growing season.

Investigators in North Dakota (48) (49) (52) (65) and South Dakota (21) call attention to the fact that as a rule durum wheat contains a somewhat higher percentage of protein than hard red spring, thus supporting Thomas and Schollenberger.

Concerning the average protein content of various classes of wheat the following statements seem warranted: (a) Durum wheat while averaging higher than hard red spring wheat, is not necessarily superior owing to the poor quality of the gluten for bread making purposes: (b) hard

spring wheat averages distinctly higher than hard red winter. Thatcher (117) attributes this difference to the shorter period of growth afforded spring wheat. Ladd (51) expresses the opinion that the difference may be due to the fact that "winter wheat matures during the part of the season when conditions are most suitable for growing and the accumulation of starch".

Variety. Numerous references call attention to the influence of variety upon the protein content of wheat. Irish and Bigelow (38) found that ten varieties of wheat which they grew in 1889 showed "a range in total nitrogen from 1.26 to 2.21 per cent". Schribaux (85) observed a variation due to varietal influence but concluded that the protein content "depends much more upon the conditions under which the plants develop". Shepard (91) noted wide variations between varieties in both common and durum wheats. Wiencko and Fisher (124) report a variation of from 10.11 to 14.45 per cent in the protein content of 59 varieties of wheat grown in Indiana in 1905. Several others, including investigators in Washington, (114) (115) (116), Kentucky (83), England (11), Pennsylvania (25), Ohio (132), Idaho (39), Kansas (130), Minnesota (6), (4), Michigan (101) and North Dakota (107) have directed attention to variations in

protein content of varieties, when grown in any one season under as nearly as possible identical conditions.

As is to be expected there are minor differences of opinion as to the importance of the variety in causing variations in protein content. Schollenberger and Clark (84) state that "the inherent qualities of a variety are the basic and usually the principal factors in determining the milling and baking value of any sample or lot of wheat", and "the effects of season, locality, rainfall, elevation, and soil are generally of less importance than varietal differences". However, the strength of this statement is reduced somewhat when the authors mention the fact that there is "considerable variation" within a variety because of the influence of environmental factors mentioning specifically the "locality and season".

The importance of the variety in influencing the protein content of wheat has been well summarized by Williams (131) and Swanson (110). The former concludes from work done in Ohio between 1901 and 1904 that "variation in per cent of protein differs radically from season to season yet some varieties which are relatively high one season are relatively high all seasons". Swanson in Kansas recognizes that certain varieties produce wheat with a higher

protein content than others, yet holds that the varietal influence is secondary to that of climate and probably also to soil. This statement agrees with the conclusions of Thatcher (116) that "the variations in the average composition of wheats grown in different localities is greater than the differences between the averages for the different varieties". Thatcher further concludes that environmental conditions exert a greater influence in determining the quality of wheat than do variety characteristics".

Source Of Seed. In 1884, Wiley (127) made public the averages analyses of wheats grown in various districts or regions of the United States. The percentage of protein ranged from 9.73 in the Pacific States to 12.74 in the Western States. It is not at all surprising; therefore, that there was developed a rather common belief that seed should be introduced occasionally from the better districts to replace that which had "run out". Irish and Biglow (38) noting the low protein content of Oregon wheat, introduced seed from three sources. The crops harvested the following year averaged 1.37 per cent less protein than the seed planted. Carleton (20)states that the gluten content of wheat cannot be "materially and permanently increased" through the introduction of "hard grained nitrogenous sorts" from another part of the country. Bolley (10) obtained

seed wheat from various sources and when tested under identical conditions, the product was approximately equal in composition. Similar results were reported by Mangels (63) and Jones and Colver (41). The work of Wiley (129), LeClerc (58), Thatcher (117) and Shaw and Walters (90) proves conclusively that the composition of the seed sown has but little influence if any on the composition of the resultant crop.

All of the evidence reviewed seems to emphasize the futility of attempting to improve the protein content of the crop by introducing seed wheat from regions which normally produce darker and stronger wheats.

Method Of Seed Bed Preparation. Available nitrogen in the soil is a product of bacterial action. Fortunately the activity of the bacteria concerned in the accumulation of nitrogen is greatly stimulated by what are recognized to be the best methods of tillage or seed bed preparation.

As early as 1893, Snyder (95) of Minnesota concluded that "the chief benefits of fallow are due to the additional time and more favorable conditions given for the process of rendering nitrogen available". Sackett (80) and Headden (34), (35) of Colorado found that the available nitrogen could be greatly increased by fallowing. McCall and Holtz (67) of Washington and Stephens and Hyslop (102) of Oregon

emphasize the importance of the early preparation of fallow in conserving moisture and accumulating nitrates. Stephens, McCall and Bracken (103) in giving the results of experiments in wheat production in the dry lands of the Western United States call attention to the fact that "tillage has a very marked effect in promoting the activities of soil bacteria" and that because of "this activity and the direct effect of soil stirring and moisture additions, the chemical make up of the soil and consequently the availability of the plant food are very materially altered by tillage". Swanson (110) gives the results of eleven year's work in Kansas showing that early preparation of the seed bed for winter wheat has a distinct advantage in both yield and protein content over late preparation. Sewell and Call (86) found the greatest amount of nitrogen in the soil at seeding time in those plats which had received some kind of early tillage in the preparation of the seed bed and Sewell and Swanson (87) noted that those tillage treatments which accumulated the largest quantity of nitrates in the soil also produced the largest yields and the wheat averaged higher in protein content and yielded flour which was superior in quality as determined by loaf volume and texture. The results of the work of Kiesselbach and Burr (46) in Nebraska agrees quite closely with those of the

Kansas experiments.

That weeds use large amounts of available nitrogen from the soil is shown by the results of experiments conducted in several states. Snyder (98) of Minnesota after analyzing 18 samples of the more common weeds, found that many of them draw from the soil large amounts of nitrogen. These results were substantiated later by the work of Sachs (79) in Arkansas. Call and Sewell (17) state that weed growth and not lack of tillage was responsible for the low nitrate content of the soil on which weeds were allowed to grow and conclude that the advantage of tillage in controlling weeds is not emphasized sufficiently. Kisselbach (46) reports that the efficiency of weed control through a "suitable combination of tillage operations has an important bearing upon available nitrates and moisture".

It seems rather obvious that tillage operations in the preparation of the seed bed for wheat can have rather marked influence upon the accumulation of available nitrogen in the soil and consequently upon the protein content of the grain.

Effect Of Crop Sequence. In 1914, Ladd and Stockham (54) state that in North Dakota the composition of wheat is affected by rotation of crops, the protein content being

higher after clover than after a cultivated crop and least where wheat follows small grain. In 1924, Swanson (110) published data showing that while wheat in rotation with alfalfa produced better yields than was obtained from the land cropped continuously to wheat, the protein content remained unchanged.

Mangels (63) in making a protein survey of the 1925 wheat crop of North Dakota, grouped the analyses according to the crop which preceded wheat. Wheat preceded by either sweet clover or bare fallow were identical in protein content but materially higher than where wheat was preceded by wheat. Wheat following corn was intermediate in protein content, ranking between wheat after wheat and wheat after fallow. Sewell and Swanson (87) reported that while certain rotations increased the yields and total protein per acre, the percentage of protein was unchanged. In 1928, Call (19) in his Annual Report of the Kansas Station compared wheat after alfalfa with wheat following wheat. The beneficial effects of cropping to alfalfa resulted in both higher yields and an increased percentage of protein.

Influence of Green Manures. In 1912, Brown (13) reported that green manuring did not always increase the number of bacteria in the soil or the ammonifying, nitrifying or nitrogen fixing power of the soil. This would infer that

the protein content of wheat following a green manure crop might not always be increased. Zook (135) in summerizing 10 year's work under dry land conditions at Scottsbluff, Nebraska, found that the green manures depressed the yields below those from bare fallow, and from this concluded that moisture was of greater importance than soil fertility in determining crop yields. Whiting and Richmond (123) of Illinois, found that more active organic matter was turned under by spring plowing of sweet clover used as a green manure than by fall plowing. Lyon and Wilson (62) working at Cornell University found rye more effective than peas in the accumulation of nitrates during the fallow period after turning under the green manure, and conclude that not all leguminous crops are more effective than non-legumes in producing a high nitrate nitrogen content during the main part of the growing season.

Time of Planting. Blanchard (9) appears to be one of the first investigators in America to note the effect of time of planting upon the protein content of wheat. Two varieties each sown early and late showed that the yields were materially reduced but the percentage of protein in the grain materially increased. In each case late planting shortened the fruiting period by 5 days. In 1913, Thatcher

(117) reported the results of four year's work in which fall seeding of certain varieties was compared with spring seeding of the same varieties. Over the 4 years, twelve varieties were so compared, the fall seedings averaging 14.29 per cent while spring sowings averaged 16.12 per cent. Olson (75) in 1923 reports similar results with Hybrid 128 sown both in the fall and in the spring. Kiesselbach (45) reports on 3 years of date-of-seeding experiments with two varieties of winter wheat and 5 year's work with one variety, Nebraska 60. In each case the protein content increased as the dates of seeding became later, also the yields decreased materially as did also the weight per bushel. Kiesselbach's work would indicate that time of planting should be governed more by test weight and yield than by the protein content. Florell (23) working in California using 4 dates of planting instead of two confirmed the results obtained by Blanchard. The protein content was increased rather sharply as the dates of planting became later, but there was an even greater decrease in yield. Obviously wheat should be planted at the time when in average seasons the largest yields of normally matured grain will be produced.

Effect Of Weathering After Maturity. With the more general use of the combined harvester-thresher in the hard red spring wheat district the question arises as to the effect

of weathering after grain has reached maturity upon the percentage of protein. The work done by Benton et al (8) and Whitcomb and Johnson (121) shows rather definitely that exposure in the field either on the standing plants or in the shock after the grain has become "dead ripe" does not materially change the percentage of protein. However, long periods of exposure particularly during stormy weather results in material decreases in the weight per bushel.

Disease. In the hard red spring wheat district, rust is one of the most serious diseases attacking the crop. Shutt (93) working in Canada found that rust arrested the development of the wheat plant and caused premature ripening, "which as we have seen, means a straw in which still remains the elaborated food, and a grain small, immature, rich in protein and deficient in starch". Harper (28) reported that the average percentage of protein in "rusted and frosted" grain in Minnesota was more than 2 per cent greater than that of wheat developed more normally. Snyder (97) also of Minnesota, found the protein content of "rusty wheat plants" to average 16.37 per cent while that of plants free from rust was 13.34 per cent.

On the other hand, Mangels (63) worked with eight varieties divided into two groups, one susceptible to rust and the other less susceptible over a period of four years.

He found one group with an average rust infection of 81 per cent to average 12.98% protein while the other with an average infection of only 48 per cent contained 14.35 per cent of protein. In making the separation of varieties into two groups Mangels introduced several variables which might have influenced the results obtained. It is possible that the less susceptible varieties were somewhat earlier in maturing, which fact alone might account for a higher protein content.

EXPERIMENTAL

Purpose Of The Study

Since 1923, the Agronomy Department of the Montana Experiment Station has collected considerable information relative to the protein content of wheat. It is the purpose of this paper to summarize the information which has been obtained and thus make it available in answering certain questions that are continually being raised by the wheat growers and grain dealers of this State. This paper deals with only seven factors which are supposed to exert more or less influence on the protein content of hard red spring wheat, namely, (a) environment or locality; (b) season, including rainfall and temperature; (c) tillage methods; (d)

manuring practices; (e) fallow vs disked corn land; (f) class of wheat; and (g) variety. In most cases, the length of time during which the investigation has been in progress is not sufficient to justify definite conclusions. However, the results now available have been summarized in an effort to provide an explanation for some of the variations that have been observed in the protein content of Montana-grown spring wheat.

Method of Procedure

All of the data reported in this paper have been obtained in connection with definite projects of investigation of the Agronomy Department of the Montana Agricultural Experiment Station.

A part of the data dealing with the influence of environment and season were obtained by the survey method, through the kind cooperation of State, Federal and private protein testing laboratories.

In certain cases, the investigational work covered by an active project was enlarged to supply additional information which was desired. In other instances, new projects were outlined in order that the information concerning the influence of certain factors on protein content

of wheat might be made more complete.

The tillage and rotation experiments of the Office of Dry Land Agriculture, United States Department of Agriculture, on the Branch Stations at Havre, Moccasin and Huntley, Montana have furnished an important part of the data used herein.

RESULTS AND DISCUSSION

Influence Of Environment Or Locality On The Protein Content

LeClerc (58) has defined environment as including all factors of any locality which might tend to influence the growth of plants, referring specifically to climatic conditions, the soil, methods of seed bed preparation and fertilizing, crop sequence, time and rate of seeding, and time of harvesting. It is obvious that environment involves several more or less closely related factors, any one of which is capable of exerting considerable influence upon the yield of the wheat crop of any season, hence it seems reasonable to expect that the combined effect of the factors constituting environment might also influence quality as expressed by the percentage of protein in the grain.

It has been known for many years that environmental

factors are capable of causing marked variations in the composition of wheat. The effects of environment have been noted in crops of wheat from different states, from different counties within any one state, from different farms within any one county, from different fields on any one farm, and in fact from different parts of any one field.

Several prominent American investigators, including Wiley (127), Carleton (20), Thatcher (116), Ladd(52), and Bailey (5) have called attention to the extent to which the protein content of wheat varies with the environment. It has been a common practice among the leading milling companies to "map" the wheat producing sections of the United States, as a guide to their buyers in making purchases of wheat containing the amount and quality of gluten desired. It is common knowledge among both elevator men and wheat growers in Montana that the method of tillage greatly influences the protein content of the crop, a fact which is bringing about improvement in both the production and marketing methods.

The data obtained in this study treat the subject of environment in relation to the protein content of wheat from three points of view, namely: (a) variation in protein content between States; (b) variation in protein content between counties in Montana, and (c) variation in protein

content between different fields on the same farm.

Variation In The Protein Content Of Marquis Wheat Grown In Different States. From 1922 to 1925, inclusive, the Montana Grain Inspection Laboratory cooperated with the Agronomy Department of ten different states in an experiment to determine the influence of environment on the milling and baking quality of Marquis wheat produced each year from Montana-grown seed. Seed for all plantings was taken from a uniform lot of grain grown near Bozeman. The protein content of the seed furnished was determined as was also that of the crop produced, a sample of which was sent to the laboratory after harvest by each cooperating state.

Table IV shows the protein content of Marquis wheat produced at the agricultural experiment station of ten different states, during 1922 to 1925, inclusive, from seed grown at Bozeman during the previous year. In 1922, seed which contained 15.23 per cent protein produced crops ranging from 15.68 per cent when grown at Moro, Oregon to 11.66 per cent protein when produced at Madison, Wisconsin. In 1923, with seed testing 13.16 per cent protein, the wheat having the maximum test, - 15.92 per cent, came from Highmore, South Dakota, while that with the minimum, 10.85 per cent was raised at St. Paul, Minnesota. The results for 1924 show that crops were harvested at Pullman, Washington

Table IV. Effect Of Environment or Locality On the Protein Content of Marquis Spring Wheat Produced From Seed Supplied Each Year From Bozoman, Montana.

Place where grown	1922	1923	1924	1925	4 yr. Ave.	3 yr. Ave.
	%	%	%	%	%	%
Seed used - grown at Bozeman	15.23	13.16	15.85	11.90	14.03	13.64
Crops Grown at						
Moccasin, Montana	-	14.64	16.33	17.40	-	15.79
Moro, Oregon	15.68	15.11	18.12	11.98	15.22	15.07
Highmore, S. D.	-	15.92	12.93	14.37	-	14.41
Fargo, N. D.	13.55	14.01	14.39	13.26	13.80	13.89
Lincoln, Nebraska	-	13.26	12.88	13.26	-	13.13
LaFayette, Indiana	14.01	14.20	12.65	10.94	12.95	12.60
Ithaca, N. Y.	11.91	11.85	10.92	13.63	12.08	12.13
Madison, Wisconsin	11.66	10.96	10.89	12.75	11.57	11.53
St. Paul, Minnesota	11.85	10.85	10.76	11.42	11.22	11.01
Pullman, Washington	12.38	11.11	10.07	10.99	11.14	10.72

and Moro, Oregon containing 10.07 and 18.12 per cent protein respectively, from seed which contained 15.85 per cent protein. In 1925, seed testing 11.90 per cent protein returned crops showing a variation from 17.40 per cent protein at Moccasin, Montana to 10.94 per cent protein at LaFayette, Indiana.

During the three years, 1923 to 1925, inclusive, the average protein content of the wheat grown in the ten states varied from 10.72 per cent at Pullman, Washington to 15.79 per cent at Moccasin, Montana, a range of slightly over five per cent due to the influence of environment.

Variation In The Protein Content Of Hard Red Spring Wheat Produced In Different Counties Of Montana. During the seven years, 1923 to 1929, inclusive, data were assembled to show the average protein content of the hard red spring wheat grown in the various counties of Montana. These data are presented in graphic form in Figures 3 to 9. In these maps, the right-hand figure within the county indicates the average protein content of the wheat grown during the year in question, while the left-hand figure is the number of analyses on which the average is based. It will be observed that the counties are shown in colors, as follows:

Green - - counties with 10.00 to 10.99 per cent protein.

Pink - - " " 11.00 to 11.99 " " "

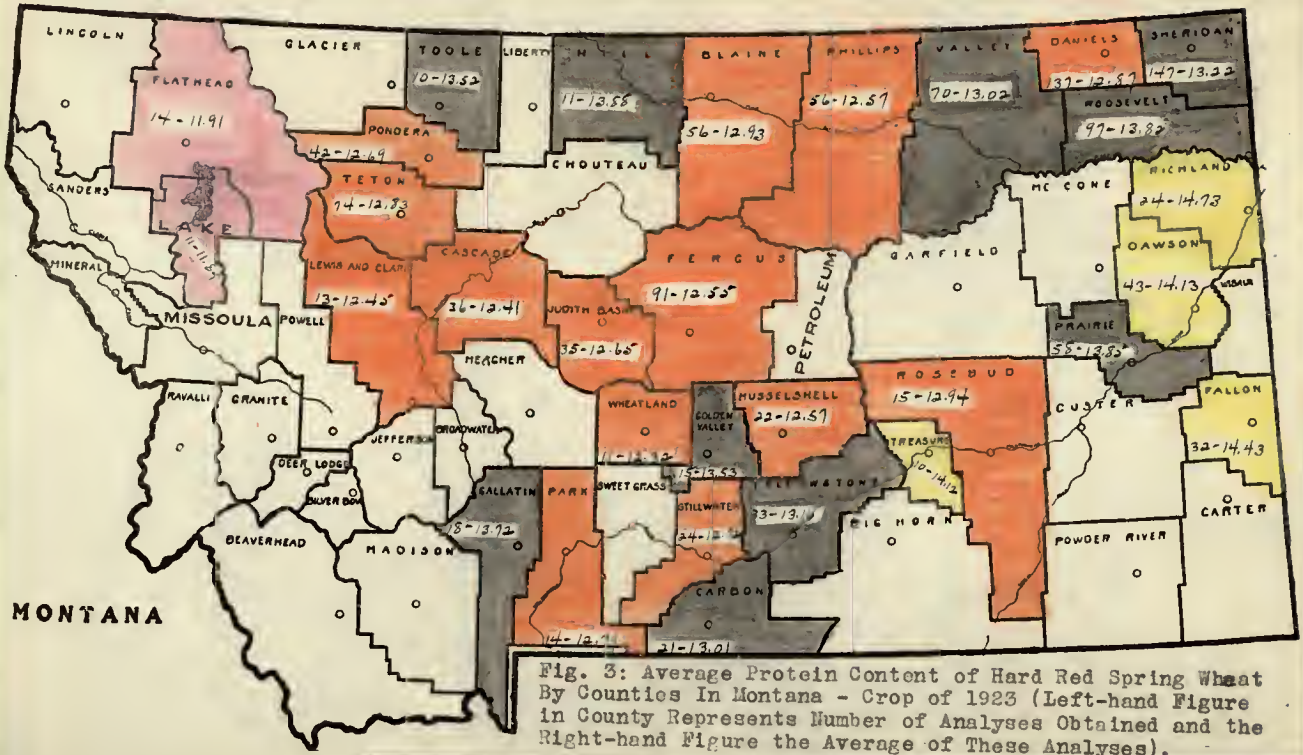

Fig. 3: Average Protein Content of Hard Red Spring Wheat By Counties In Montana - Crop of 1923 (Left-hand Figure in County Represents Number of Analyses Obtained and the Right-hand Figure the Average of These Analyses).

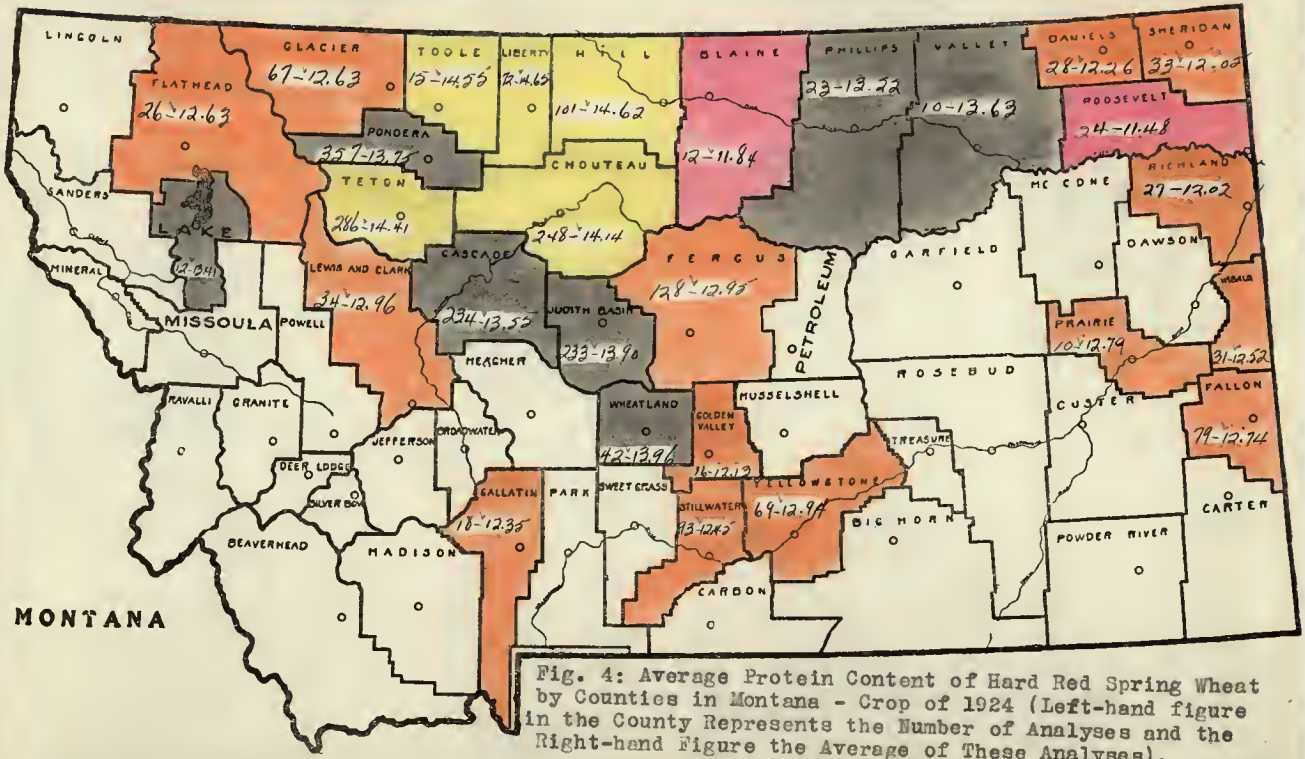

Fig. 4: Average Protein Content of Hard Red Spring Wheat by Counties in Montana - Crop of 1924 (Left-hand figure in the County Represents the Number of Analyses and the Right-hand Figure the Average of These Analyses).

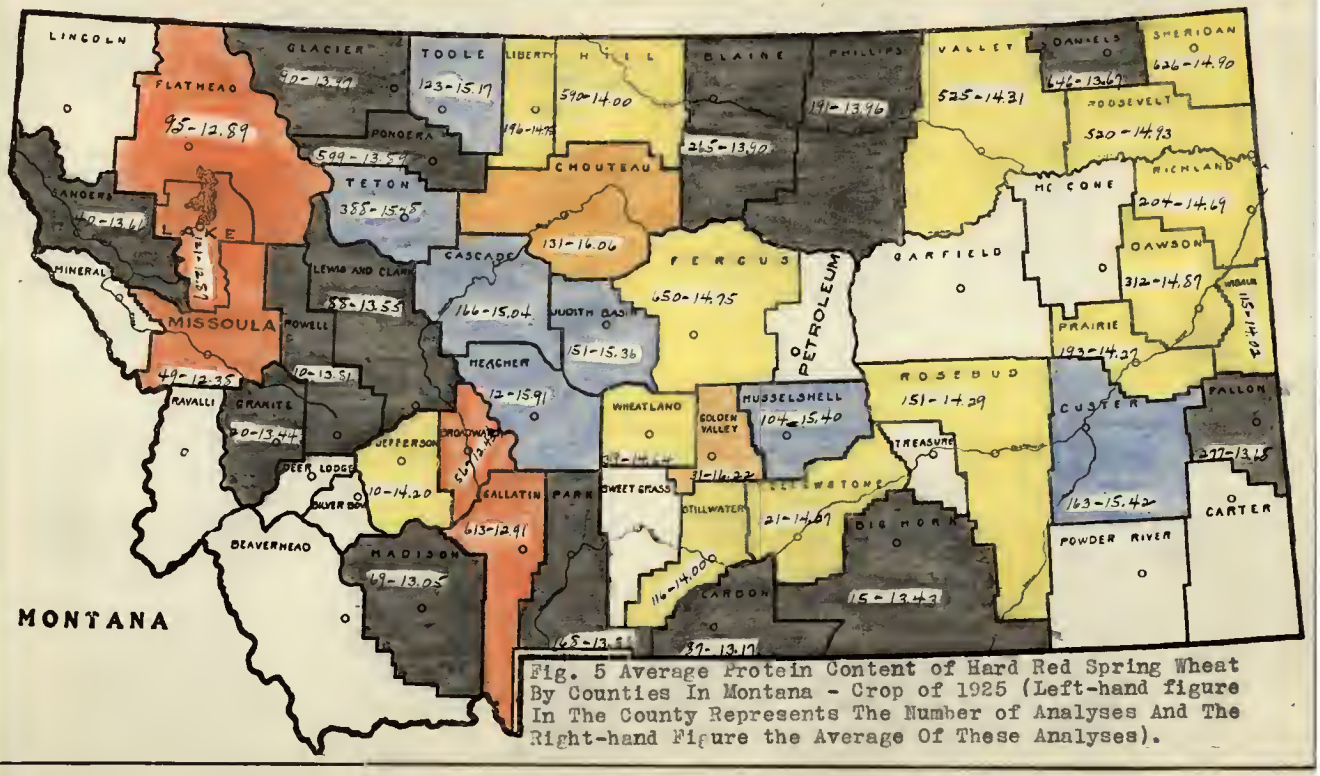

Fig. 5 Average Protein Content of Hard Red Spring Wheat By Counties In Montana - Crop of 1925 (Left-hand figure In The County Represents The Number of Analyses And The Right-hand Figure the Average Of These Analyses).

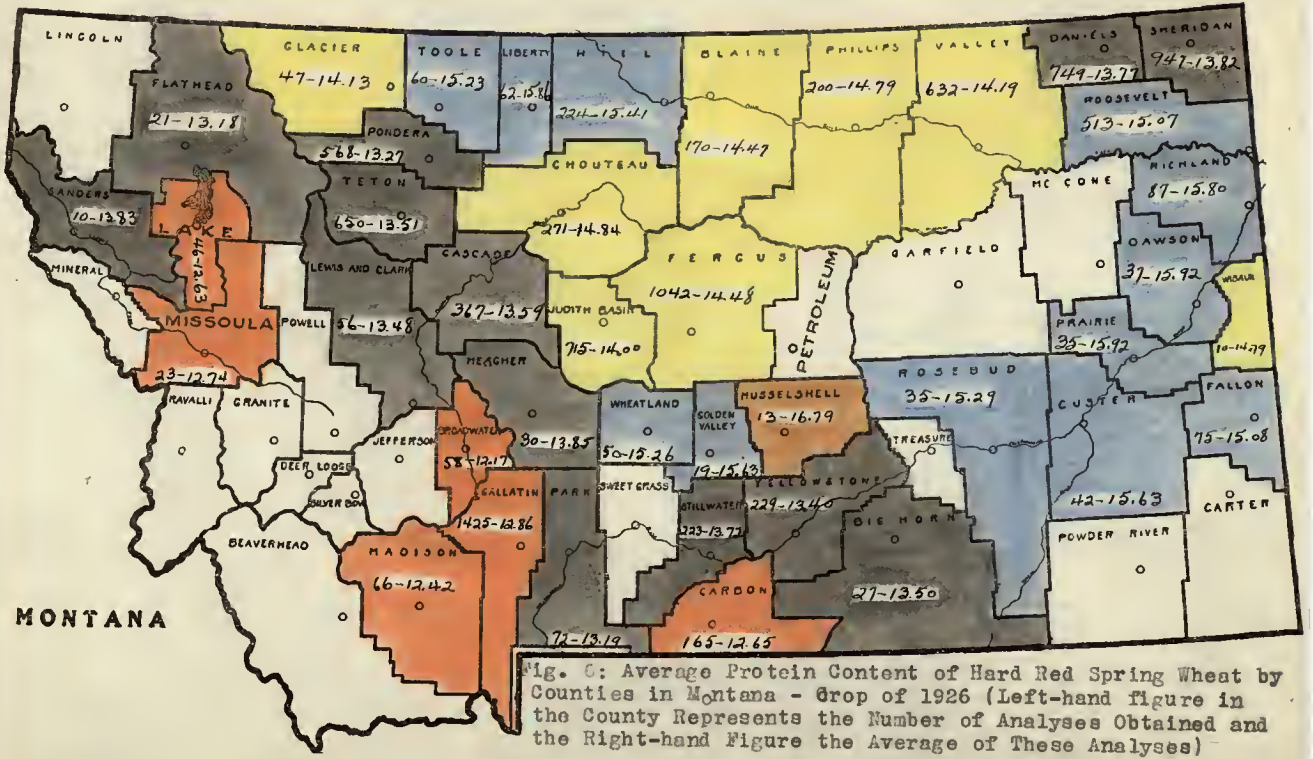

Fig. 6: Average Protein Content of Hard Red Spring Wheat by Counties in Montana - Crop of 1926 (Left-hand figure in the County Represents the Number of Analyses Obtained and the Right-hand Figure the Average of These Analyses)

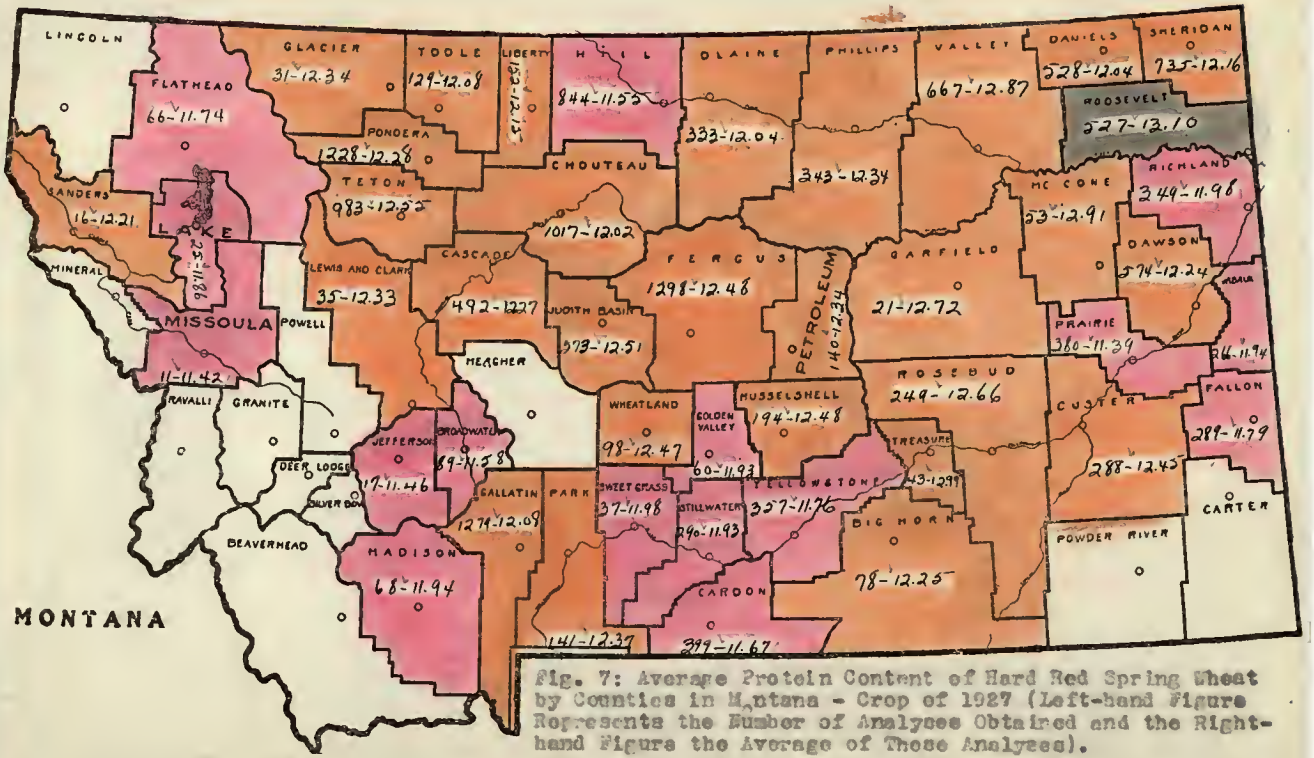

Fig. 7: Average Protein Content of Hard Red Spring Wheat by Counties in Montana - Crop of 1927 (Left-hand Figure Represents the Number of Analyses Obtained and the Right-hand Figure the Average of Those Analyses).

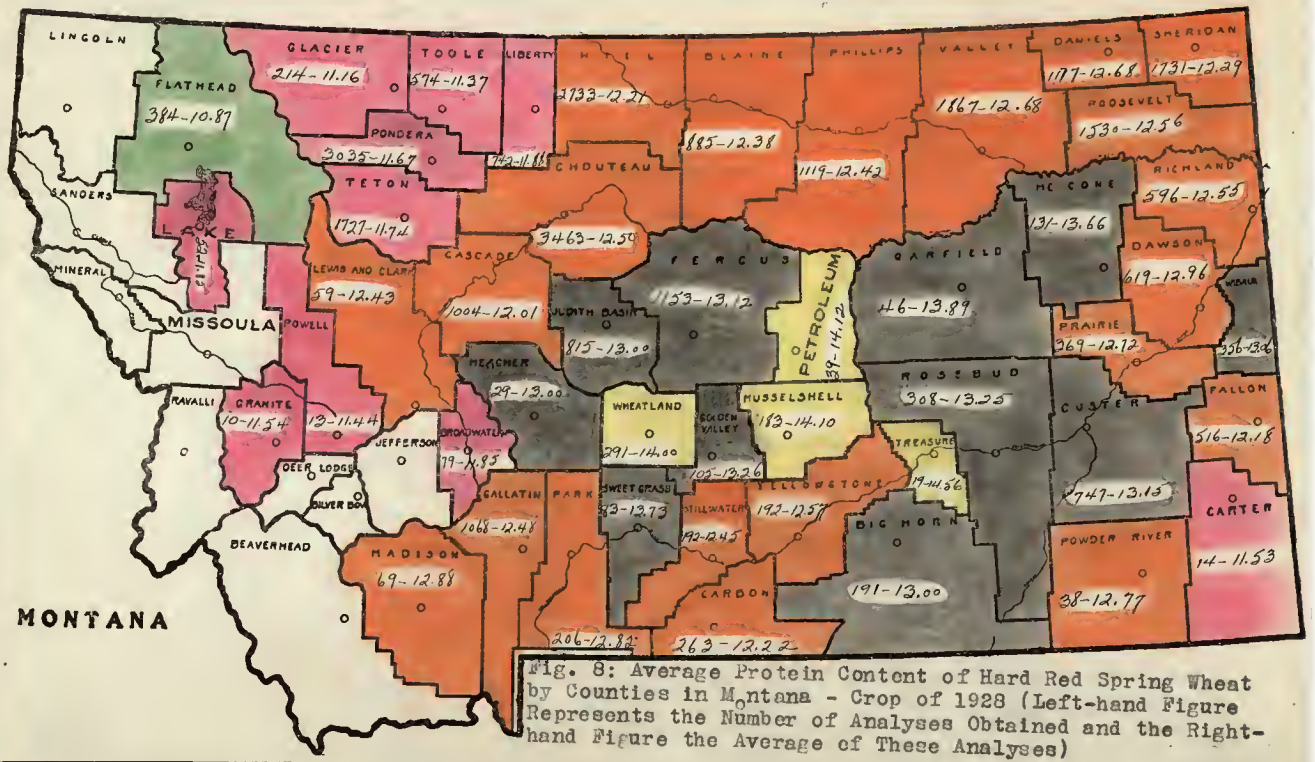

Fig. 8: Average Protein Content of Hard Red Spring Wheat by Counties in Montana - Crop of 1928 (Left-hand Figure Represents the Number of Analyses Obtained and the Right-hand Figure the Average of These Analyses)

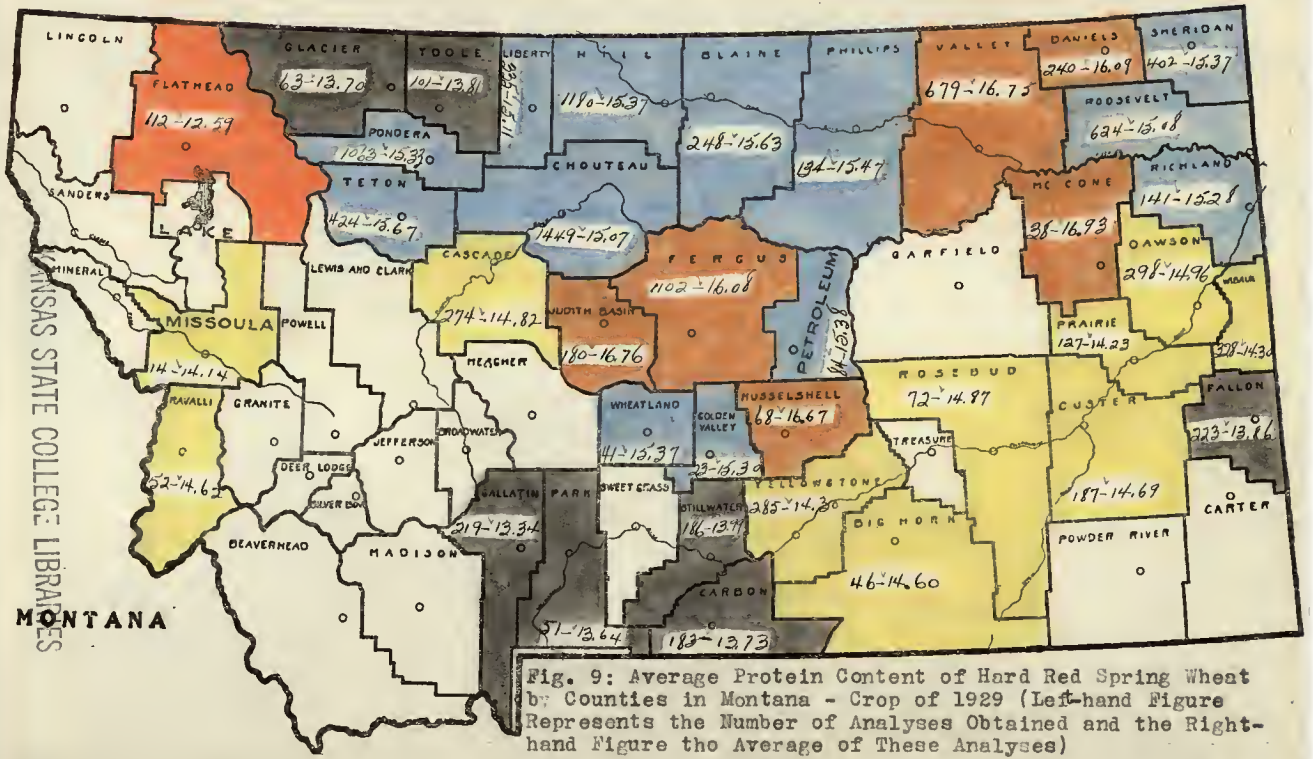

Fig. 9: Average Protein Content of Hard Red Spring Wheat by Counties in Montana - Crop of 1929 (Left-hand Figure Represents the Number of Analyses Obtained and the Right-hand Figure the Average of These Analyses)

KANSAS STATE COLLEGE LIBRARIES

Orange - counties with 12.00 to 12.99 per cent protein
Black " " 13.00 to 13.99 " " "
Yellow " " 14.00 to 14.99 " " "
Blue " " 15.00 to 15.99 " " "
Brown " " 16.00 to 16.99 " " "

These maps not only point out the variation in protein content from season to season but they emphasize the differences in the percentage of protein in the wheat from the different counties within any one year. Table V shows the minimum and maximum county averages, and also the state average protein content for each year, 1923 to 1929, inclusive, During this period of seven years, the counties with the lowest seasonal average protein content were located in the western one-third or inter-mountain region of the state five times, while in two years, 1924 and 1927, the low protein county was located in eastern Montana.

Figure 10 which has been prepared on the basis of comparable five-year averages for 38 counties points out rather definitely where wheat with a low average protein content, one year with another is produced. Without exception, the low protein wheat, on the average comes from counties either in or adjacent to the Rocky Mountains. Of the eight counties in which the hard red spring wheat has averaged less than 13.00 per cent protein during this five-year period, only

Table V. Data From Figures 3 to 9 Showing Counties With Minimum and Maximum Average Protein Content of Hard Red Spring Wheat, From 1923 to 1929, With Annual State Average For Comparison.

Year	Minimum - - - County		Maximum - - - County		State Ave.
1923	11.84%	Lake	14.73%	Richland	13.12%
1924	11.48%	Roosevelt	14.65%	Liberty	13.55%
1925	12.38%	Missoula	16.22%	Golden Valley	14.29%
1926	12.17%	Broadwater	16.79%	Musselshell	13.91%
1927	11.39%	Prairie	13.10%	Roosevelt	12.21%
1928	10.87%	Flathead	14.56%	Treasure	12.39%
1929	12.59%	Flathead	16.93%	McCone	15.22%

one or two are really important wheat producers. Musselshell was the premier high protein county although its average exceeds that of several other central Montana counties by only a small margin. On the basis of the acreage and production of spring wheat in Montana in 1928, the 30 counties in which the average protein content exceeds 13.00 per cent, account for 61,307,000 bushels or approximately 95 per cent of the state's total production of that crop. The data on which Figure 10 is based are presented in Table VI.

Variation In The Protein Content Of Spring Wheat Grown Under Different Tillage Methods On The Same Farm. Dry land tillage experiments with spring wheat are conducted cooperatively by the Montana Agricultural Experiment Station and the United States Department of Agriculture at the Northern Montana Branch Station in Hill county, at the Judith Basin Branch Station in central Montana, and at the Huntley Branch Station in Yellowstone county. These experiments afford an opportunity to compare the protein content of spring wheat grown on clean fallow with that grown on land cropped to wheat every year, the seed bed being prepared by spring plowing.

The data presented in Table VII tend to support the observations of many Montana wheat growers that the protein

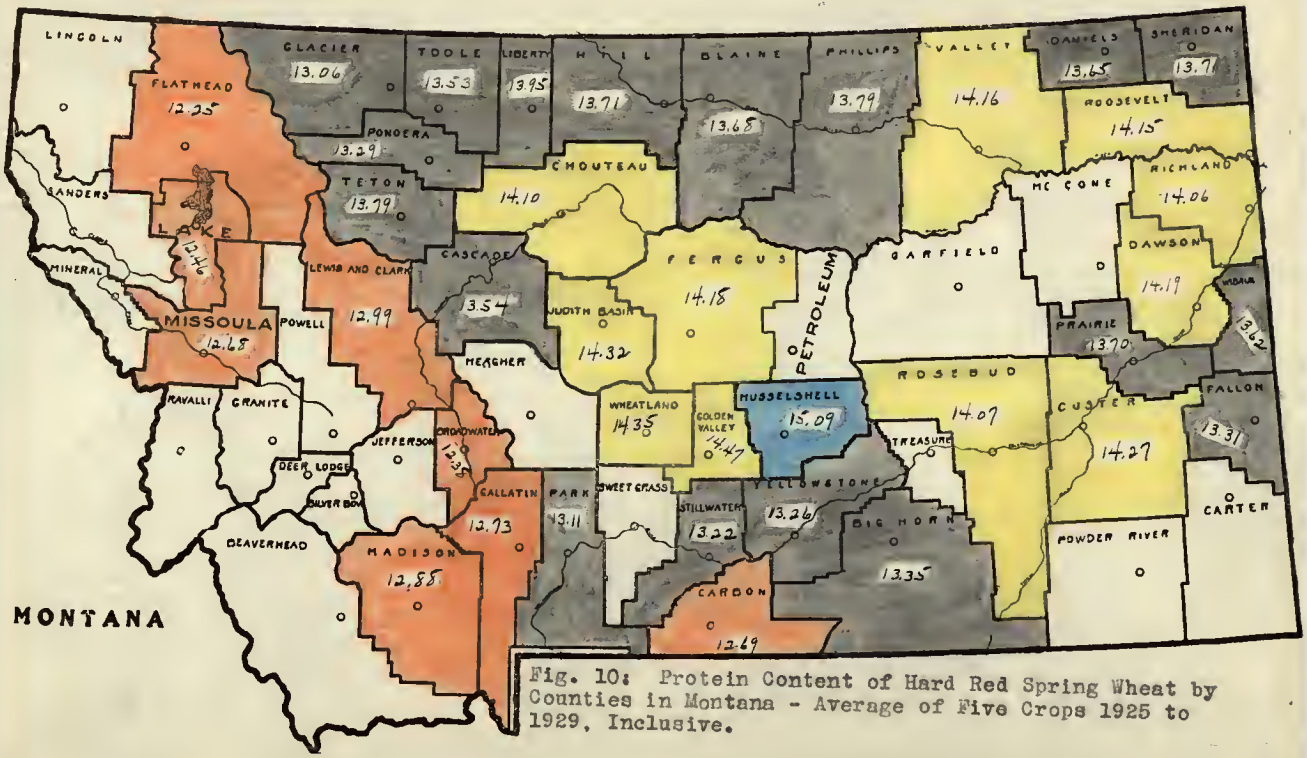

Fig. 10: Protein Content of Hard Red Spring Wheat by Counties in Montana - Average of Five Crops 1925 to 1929, Inclusive.

Table VI. Thirty-eight Montana Counties Ranked According to the Average Protein Content of Hard Red Spring Wheat During a Five-year Period, 1925 to 1929, Together With Minimum and Maximum Averages and Years in Which Recorded.

County	Five Year Rank	Five Year Ave. Protein %	Low %	Year	High %	Year
Musselshell	1	15.09	12.48	1927	16.79	1926
Golden Valley	2	14.47	11.93	1927	16.22	1925
Wheatland	3	14.35	12.47	1927	15.37	1929
Judith Basin	4	14.32	12.51	1927	16.76	1929
Custer	5	14.27	12.45	1927	15.63	1926
Dawson	6	14.19	12.24	1927	15.92	1926
Fergus	7	14.18	12.48	1927	16.08	1929
Valley	8	14.16	12.68	1928	16.75	1929
Roosevelt	9	14.15	12.56	1928	15.08	1929
Chouteau	10	14.10	12.02	1927	16.06	1925
Rosebud	11	14.07	12.66	1927	15.29	1926
Richland	12	14.06	11.98	1927	15.80	1926
Liberty	13	13.95	11.88	1928	15.86	1925
Phillips	14	13.79	12.34	1927	15.47	1929
Teton	15	13.79	11.74	1928	15.67	1929
Sheridan	16	13.71	12.16	1927	15.37	1929
Hill	17	13.71	11.55	1927	15.41	1926
Prairie	18	13.70	11.39	1927	15.92	1926
Blaine	19	13.68	12.04	1927	15.63	1929
Daniels	20	13.65	12.04	1927	16.09	1929
Wibaux	21	13.62	11.94	1927	14.79	1926
Cascade	22	13.54	12.01	1928	15.04	1925

(Table VI - Continued)

County	Rank	Five Year Ave. Protein %	Low %	Year	High %	Year
Toole	23	13.53	11.37	1928	15.23	1926
Big Horn	24	13.35	12.25	1927	14.60	1929
Fallon	25	13.31	11.79	1927	15.08	1926
Pondera	26	13.29	11.67	1928	15.33	1929
Yellowstone	27	13.26	11.76	1927	14.30	1929
Stillwater	28	13.22	11.93	1927	14.00	1925
Park	29	13.11	12.37	1927	13.64	1929
Glacier	30	13.06	11.16	1928	14.13	1926
Lewis & Clark	31	12.99	12.33	1927	13.55	1925
Madison	32	12.88	11.94	1927	14.13	1929
Gallatin	33	12.73	12.08	1927	13.34	1929
Carbon	34	12.69	11.67	1927	13.73	1929
Missoula	35	12.68	11.42	1927	14.14	1929
Lake	36	12.46	11.85	1928	13.08	1929
Broadwater	37	12.38	11.58	1927	13.86	1929
Flathead	38	12.25	10.87	1928	13.18	1926

Table VII: Protein Content of Spring Wheat Grown On Clean Fallow Compared With That of Spring Wheat Grown on Land Continuously Cropped to Wheat but Spring Plowed, at the Northern Montana Branch Station at Havre, the Judith Basin Branch Station at Moccasin and at the Huntley Branch Station at Huntley.

Plot and Tillage		Havre 1925-1929	Moccasin 1925-29	Huntley 1928-29
MC-C&D	Fallow	15.75%	15.92%	17.07%
MC-A	Spring Plowed	12.94%	15.59%	15.93%

protein content of spring wheat from two fields on the same farm may vary as much as two per cent, the advantage going to the wheat from the field which received the most thoro preparation of the seed bed.

Considered from any one of the three points of view, the data submitted strongly substantiate the general statement that the environment or the locality may materially influence the protein content of spring wheat in any one season. It is also apparent that one combination of environmental factors may produce wheat with a rather low average protein content over a period of years while in another locality with a different environment, a relatively high average protein content results. However, it is possible to outline or designate the areas of high and low average protein content only in a very general way

because of the wide seasonal fluctuations.

Influence Of The Season On The Protein Content

Through the kind cooperation of various agencies it has been possible to obtain information relative to the point of origin and protein content of 81,222 samples of Montana hard red spring wheat from the crops of 1923 to 1929, inclusive. This information has afforded an excellent opportunity to study the influence of the season on the protein content of wheat.

The data for each year were assembled by shipping points and by counties. The volume of the information thus obtained is too great to be included as a part of this paper, hence a summary table only is used.

Seasonal Variations In Protein Content Of Montana Spring Wheat. During the seven years, 1923 to 1929, inclusive, Montana-grown hard red spring wheat has had an average protein content of 13.53 per cent, the annual average varying from a minimum of 12.21 per cent in 1927 to a maximum of 15.22 per cent in 1929, a range of 3.01 per cent. (See Table VIII)

Crop Of 1923 And Seasonal Conditions. The 1923 crop of hard red spring wheat averaged 13.12 per cent protein, based on the analyses of 1,322 samples. The moisture supply during

Table VIII - Average Protein Content of Hard Red Spring Wheat In Montana by Years - 1923 to 1929

	1923	1924	1925	1926	1927	1928	1929	Ave.
Samples Analyzed	1322	2394	9171	10101	15826	31071	11337	-
Ave. Per Cent Protein	13.12	13.55	14.29	13.91	12.21	12.39	15.22	13.53* ± .29

*Arithmetical average used because of the variation in the number of samples analyzed in the different years.

April and May, while slightly below normal, was quite favorable for starting the crop. However, heavy June rains over practically all of the state were extremely beneficial and conditions were further improved by the July and August precipitation which was above normal. July was the hottest month of that name in many years, with a mean temperature of 69.2° F., 3.5° above normal.

While short periods of drought and hot winds during the growing season in the eastern fifth of the state materially reduced yields in that section, the yield for the state as a whole averaged 14.0 bushels per acre, with an average test weight of 59.8 pounds per bushel. There is nothing particularly striking about the seasonal conditions of 1923 in relation to protein content, except the effects of the drought and hot winds in the eastern end of the state. The map for 1923 (Figure 3) shows that the wheat from the eastern Montana counties average high in protein content. Crop Of 1924 And Seasonal Conditions. The wheat crop harvested in 1924 averaged 13.55 per cent protein, based on the analyses of 2394 samples. Broadly speaking, the crop season was cool and dry. From April 1 to August 31, the precipitation was 2.19 inches below normal for that period and the temperatures ranged from 0.8 degrees above normal in May to 2.7 degrees below normal in June.

Rains which became general throughout the State about the close of June ended the drought. The cool growing season and the absence of hot winds during the filling period resulted in good yields, the State average for spring wheat being 16.2 bushels per acre. The average test weight per bushel was 59.5 pounds.

Crop Of 1925 And Seasonal Conditions. Analyses of 9171 samples of Montana-grown hard red spring wheat of the 1925 crop showed an average protein content of 14.29 per cent. With March and April temperatures somewhat higher than normal and a moderate excess of precipitation, the crop started under favorable conditions. May was unusually warm and rains for that month were below the mean. However, June was about a normal month, and with the exception of scattered localities, the prospects for a good crop of spring wheat were quite favorable. July opened dry and warm, and by the end of that month, grain crops, particularly in the eastern districts had been quite badly damaged. The dry weather continued through the first half of August, forcing much grain to ripen prematurely, with low yields of light weight grain. For the State as a whole, spring wheat averaged 10.5 bushels per acre with an average test weight of 58.0 pounds per bushel.

Crop Of 1926 And Seasonal Conditions. In 1926, 10101 samples of hard red spring wheat averaged 13.91 per cent protein. The average yield for the state was 12.3 bushels per acre and the test weight was 58.5 pounds per bushel. The months of April to July, inclusive, were characterized by temperatures above normal and rainfall below normal. In much of the State east of the Rocky Mountains, the deficiency in the 1926 precipitation combined with a light winter reserve of soil moisture, interfered seriously with crop prospects. June rains came in time to be of considerable benefit although some permanent damage to the yield of spring wheat had already been done.

Crop Of 1927 And Seasonal Conditions. The season of 1927 produced wheat with the lowest average protein content recorded during the seven year period. Analyses of 15826 samples of hard red spring wheat showed an average of 12.21 per cent of protein for the State as a whole. Reserve supplies of soil moisture from the rains of the preceding fall started the crop under what were probably the most favorable conditions in years. May, in addition to being the coldest month of that name since 1899, broke all records for rainfall, with a total of 5.15 inches for the month, 2.92 inches above normal. However, beginning with early June, conditions became more favorable and crops

progressed rapidly. Well distributed showers and the absence of hot winds carried the crops through the critical period in July without injury. By the first of August, most crops of spring wheat had over come the late start.

The five-month period, April to August, inclusive, closed with a precipitation of 3.22 inches in excess of normal considering the entire State. Temperatures during this time ranged from 0.1° above normal in June to 4.2° below in May. The combined effects of an abundance of moisture and temperatures below normal, especially in July and August resulted in unusually good yields of grain. The average yield of spring wheat in Montana in 1927 was 20.6 bushels per acre and tested 59.4 pounds per bushel.

Crop Of 1928 And Seasonal Conditions. The season of 1928 was dry and fairly warm, the State-wide averages of precipitation and temperature being 13.06 inches and 43.3° F. respectively. While the precipitation for February, March and April was below normal and May was the driest month of that name on record since 1895, the rains during June were generous and well distributed, followed by the wettest July since 1915. August rainfall also was above normal.

The weather conditions during June, July and August, including temperatures which were practically normal, combined with above normal rainfall offset the early spring

drought with the result that spring wheat yields averaged high, 19.0 bushels per acre being the State average. The protein content averaged 12.39 per cent based on 31071 analyses. The average test weight was 59.7 pounds per l[illegible] bushel.

Crop Of 1929 And Seasonal Conditions. The season of 1929 goes down in Montana's climatological record as cool and dry, the State-wide temperature averaging 40.9° F., a departure of -1.4° from the mean and precipitation averaging 13.08 inches, 2.36 inches below normal. A mild March followed one of the coldest winters recorded since the beginning of State-wide records in 1895. April, May and June were unseasonably cool, with precipitation almost two inches below the average for that period. July and August were unusually hot and dry, with the result that the small grain yields were materially reduced.

For the State as a whole, spring wheat averaged 9.0 bushels per acre with a test weight of 58.0 pounds per bushel. Analyses of 11337 samples showed an average protein content of 15.22 per cent, the highest State average yet recorded.

Relation Of Rainfall To The Protein Content Of Wheat. Season is a general term involving several variable factors, important among which are sunshine, temperature, humidity,

rainfall and winds. In the Northern Great Plains where the average annual precipitation varies from 10 to 20 inches, moisture frequently is the limiting factor in crop production.

A review of the literature suggests that rainfall and temperature, particularly during the growing season may cause wide fluctuations in the protein content of wheat from year to year. Under the sub-humid conditions of the Northern Great Plains, where from 50 to 60 per cent of the annual precipitation is received during the months of April to August inclusive, it seems entirely possible that wide departures of either moisture or temperature from the means of that period might have a marked influence on the protein content of the spring wheat crop.

Applied To The State As A Whole. Table IX gives the mean monthly precipitation for Montana, for the seven years, 1923 to 1929, inclusive, compiled from the summaries of the United States Weather Bureau. The degree of association or correlation between the rainfall for each month of the growing season and the protein content of spring wheat is measured by calculating the correlation coefficient according to a formula offered by Hayes and Garber (31).

The data for the State as a whole, given in Table X show a significant negative correlation, $-.949 \pm .025$,

Table IX: Mean Monthly Precipitation for Montana From 1923 to 1929 With Average, Also Precipitation Totalled by Periods, Annual; April to August and July and August. (Compiled from U. S. Weather Bureau Summaries).

Month	1923	1924	1925	1926	1927	1928	1929	Ave.
January	1.20	0.68	1.07	0.59	0.88	0.98	0.91	0.90
February	0.58	0.84	0.73	0.69	0.87	0.30	0.64	0.66
March	0.64	1.20	1.13	0.38	0.61	0.75	1.20	0.84
April	1.08	0.79	1.85	0.40	1.20	0.91	0.94	1.02
May	2.16	0.84	1.36	1.59	5.15	0.67	1.71	1.92
June	3.99	2.73	2.83	2.10	1.91	3.27	2.14	2.71
July	2.34	1.12	1.31	1.16	1.68	2.47	0.59	1.52
August	1.69	1.00	0.89	1.60	2.04	1.37	0.34	1.27
September	1.37	0.87	2.38	2.44	1.69	0.34	1.35	1.47
October	1.32	1.27	1.46	0.53	1.22	0.93	0.86	1.08
November	0.79	1.28	0.40	1.52	2.24	0.34	0.58	1.02
December	0.96	1.09	0.93	0.79	1.14	0.73	1.22	0.98
Annual	18.12	13.71	16.34	13.79	20.63	13.06	13.08	15.53
April-August	11.26	6.48	8.24	6.85	11.98	8.69	5.72	8.46
June-July	6.33	3.85	4.14	3.26	3.59	5.74	2.73	4.23
July-Aug.	4.03	2.12	2.20	2.76	3.72	3.84	0.93	2.80

Table X: Degree Of Correlation Between The Mean Monthly Precipitation During the Growing Season and the Average Protein Content of Hard Red Spring Wheat for the Seven years - 1923 to 1929, Inclusive.

	April	May	June	July	August	June & July	July & Aug.	April to August
Ave. of State								
Value of "r"	-.537	-.361	-.278	-.737	-.703	-.538	-.949	-.797
P. E. of "r"	±.181	±.221	±.235	±.116	±.128	±.181	±.025	±.092
3 x P.E. of "r"	.543	.663	.705	.348	.384	.543	.075	.276
Fallon County								
Value of "r"	-.526	-.212	-.051	-.550	-.003	-.573	-.418	-.665
P. E. of "r"	±.184	±.243	±.254	±.177	±.254	±.171	±.210	±.142
3 x P.E. of "r"	.552	.729	.762	.531	.762	.513	.630	.426
Phillips County								
Value of "r"	-.311	-.157	-.676	-.855	-.707	-.828	-.871	-.829
P. E. of "r"	±.230	±.248	±.138	±.068	±.127	±.079	±.061	±.079
3 x P. E. of "r"	.690	.744	.414	.204	.381	.237	.183	.237
Hill County*								
Value of "r"	-.248	-.548	-.184	-.843	-.822	-.441	-.669	-.740
P. E. of "r"	±.258	±.192	±.266	±.079	±.261	±.221	±.152	±.124
3 x P. E. of "r"	.774	.576	.798	.237	.783	.663	.456	.372

*Data for 6 years - 1924 to 1929, inclusive.

Table X (Continued)

	April	May	June	July	August	June & July	July & Aug.	April to May
Teton County								
Value of "r"	+.529	-.426	+.065	-.717	-.670	-.554	-.790	-.707
P. E. of "r"	±.183	±.206	±.253	±.123	±.140	±.176	±.095	±.127
3 x P.E. of "r"	.549	.624	.759	.369	.420	.528	.285	.381

between the average protein content of Montana-grown hard red spring wheat and the total rainfall for the months of July and August, based on the seven-year period, 1923 to 1929, inclusive. During the same period, there was a significant negative correlation, -.797±.092, between the protein content and the total rainfall for the five months, April to August, inclusive. There are also significant negative correlations between the protein content and the rainfall for the individual months of July and August. Figure 11 illustrates clearly the distinct tendency for the protein content of spring wheat to vary inversely as the total rainfall for July and August.

The close association of the protein content with the total rainfall during the growing season noted above agrees with the results reported by Bailey (5) of Minnesota who found that "there is a relationship between the rainfall from April 1 to September 1 and the protein content, and with the findings of Stewart and Hirst (106) of Utah who report that there is "a close relation" between the rainfall during the growing season and the protein content of wheat. Applied To Individual Counties. Montana is a large State, with wide variations in rainfall both in the total amount and in the distribution. It will be of value, therefore, to examine the correlation between the rainfall and the protein

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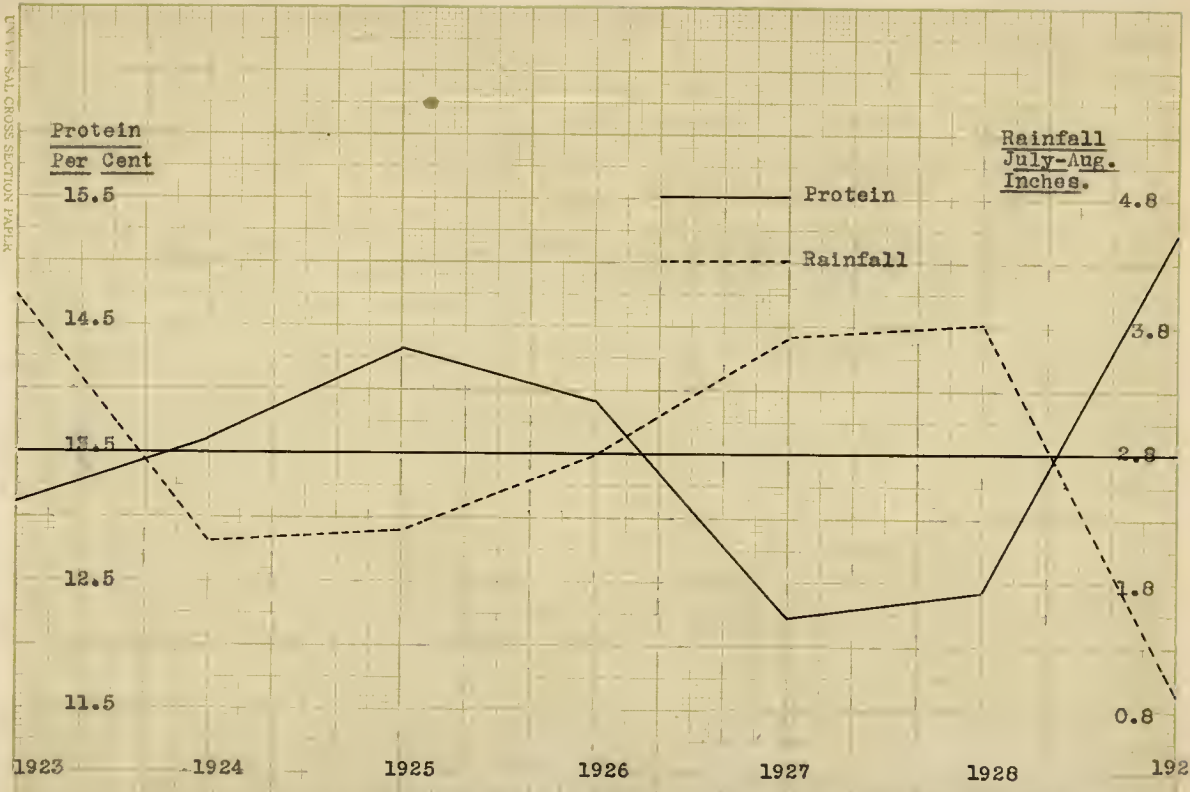


Fig. 11 - Relation Between The Total Mean Rainfall For July and August And the Average Protein Content of Hard Red Spring Wheat in Montana, 1923 to 1929, Inclusive.

content of wheat grown in individual counties in various parts of the State. For this purpose four counties were selected, namely, Fallon, in the extreme eastern part of Montana, Phillips and Hill, in the northcentral district, and Teton, just east of the Rocky Mountains in the western one-third of the State. Counties were chosen in which rainfall and temperature records were available from a more or less central point and in which the seasonal protein averages were based on a sufficient number of analyses to make them fairly representative of the wheat from the county in question.

The data showing the correlation between the seasonal protein content and the monthly rainfall during the growing season for the four counties are given in Table X. A study of these data bring out the fact that correlations which may apply for one county or set of environmental conditions are not necessarily applicable to another part of the State. In Fallon County (average annual rainfall, at Plevna, 1923 to 1929 - 13.79 inches) the most significant correlation between the rainfall for any one month and the protein content is that for July, -.550 ±.177. There is almost no correlation between the August rainfall and protein content, no doubt due largely to the fact that in this county, much

of the spring wheat is harvested before August 1. In Phillips county (average annual precipitation at Malta, 1923 to 1929 - 15.25 inches) where the wheat crop averages somewhat later in maturity than in Fallon county, the rainfall for both July and August appear to be fairly closely related to the protein content, $-.855 \pm .068$ and $-.707 \pm .127$ respectively. In Hill county (average annual precipitation at Havre, 1923 to 1929 - 14.73 inches) only the July rainfall appears to be definitely related to the protein content. In Teton county (average annual precipitation at Chouteau - 1923 to 1929 - 13.45 inches) the rainfall during both July and August appears to be significant in relation to the protein content of the wheat crop.

In each of the four counties, there is a significant negative correlation between the rainfall for the five months, April to August, inclusive, and the protein content, and with the exception of Fallon county, the same is true for the combined rainfall for July and August. These data compare favorably with those for the State as a whole and also agree with the findings of Bailey and those of Stewart and Hirst previously noted.

Applied To An Individual Farm. The Montana Agricultural Experiment Station cooperates with the United States Department of Agriculture in conducting tillage experiments with

wheat under dry land farming conditions. The MC-C and D plots - alternate wheat and fallow, and the MC-A plot - continuous wheat on spring plowing furnish an opportunity to determine whether the rainfall during any particular month or group of months during the growing season is correlated with the protein content of durum wheat grown on a uniform soil but under different tillage conditions on one farm. Because of the fact that the product of but a single plot during a period of only five years is involved in each case, the results are likely to be rather variable and perhaps lacking somewhat in value. However, the data are of interest and are presented in Table XI.

It will be observed that the correlations in the two cases vary considerably which suggests the possibility that the effectiveness of the rainfall during the various months and consequently its relation to the protein content of wheat may be influenced materially by the tillage method.

It is interesting to note the significant negative correlation between the July rainfall and the protein content of the wheat grown both on the fallow and on the continuously cropped land. In both cases also, there is a significant negative correlation between the protein content and the combined rainfall for July and August.

Table XI: Degree Of Correlation Between The Mean Monthly Precipitation During the Growing Season and the Average Protein Content of Durum Wheat On Fallow and on Continuous Cropping at the Northern Montana Branch Station - 1925 to 1929.

	April	May	June	July	August	June & July	July & Aug.	April to Aug.
Alternate Wheat and fallow								
Value of "r"	+.004	-.468	+.115	-.781	+.260	-.244	-.610	-.414
P. E. of "r"	±.301	±.235	±.297	±.117	±.281	±.283	±.189	±.249
3 x P. E. of "r"	.903	.705	.891	.351	.843	.849	.567	.747
Continuous cropping.								
Value of"r"	-.460	-.049	-.746	-.670	-.342	-.883	-.887	-.672
P. E. of "r"	±.237	±.300	±.133	±.166	±.266	±.066	±.064	±.165
3 x P. E. of "r"	.711	.900	.399	.498	.798	.198	.192	.495

Relation Of Temperature To Protein Content. The literature suggests that temperature probably ranks next to rainfall among the seasonal factors known to influence the protein content of a crop of wheat.

While the temperatures during the months of the growing season in the Northern Great Plains average lower than those of the southwest, or the hard winter wheat belt, there is considerable variation above or below the mean, resulting occasionally in what are regarded as "hot" or "cold" seasons. In this paper, correlations between mean monthly temperatures and protein content have been calculated in the same manner as for precipitation. However, no attempt has been made to study the effect of temperature over two and five-month periods.

Applied To The State As A Whole. Table XII presents the mean monthly temperatures for Montana for the years 1923 to 1929, inclusive, as compiled from the Annual Summaries of the Weather Bureau of the United States Department of Agriculture. The correlation coefficient together with the probable error and least significant difference (three times the probable error) between the mean temperature for each month of the growing season and the average protein content of Montana hard red spring wheat are given in Table XIII. Considering the State as a whole, the mean temperature

Table XII: Mean Monthly Temperatures For Montana From 1923 to 1929 Inclusive With Annual Averages (Compiled From Summaries, United States Weather Bureau.)

Month	1923	1924	1925	1926	1927	1928	1929	7 yr. ave.
January	25.4	15.5	23.1	25.4	18.7	22.3	7.3	19.7
February	17.1	31.5	30.4	32.4	22.7	24.2	12.6	24.4
March	30.4	29.0	34.1	35.0	32.9	35.6	34.3	33.0
April	41.6	41.1	46.8	45.9	40.6	39.6	39.4	42.1
May	51.8	52.4	54.4	54.3	46.7	57.3	49.7	52.4
June	59.6	57.1	60.3	60.6	59.5	56.1	58.7	58.8
July	69.2	66.1	68.3	69.1	65.5	66.3	68.5	67.6
August	63.8	63.1	64.5	64.3	62.5	62.5	69.3	64.3
September	57.3	55.4	55.1	48.3	54.1	55.3	51.0	53.8
October	42.7	46.6	35.3	47.2	47.6	43.2	46.4	44.1
November	36.7	31.4	33.2	32.2	29.2	33.6	30.4	32.4
December	25.0	13.0	30.0	21.4	9.6	23.8	22.9	20.8
Annual	43.4	41.8	44.6	44.7	40.8	43.3	40.9	42.8

Table XIII: Degree Of Correlation Between The Mean Monthly Temperatures During The Growing Season And The Average Protein Content Of Hard Red Spring Wheat For The Seven Seasons, 1923 to 1929.

	April	May	June	July	August
Average of State					
Value of "r"	+.391	-.218	+.205	+.512	+.940
P. E. of "r"	±.215	±.242	±.244	±.188	±.029
3 x P. E. of "r"	.645	.726	.732	.564	.087
Fallon County					
Value of "r"	+.511	+.409	+.849	+.937	+.593
P. E. of "r"	±.188	±.212	±.071	±.031	±.165
3 x P. E. of "r"	.564	.636	.213	.093	.495
Phillips County					
Value of "r"	+.827	-.044	+.279	+.651	+.758
P. E. of "r"	±.208	±.254	±.235	±.146	±.108
3 x P. E. of "r"	.624	.762	.705	.438	.324
Hill County					
Value of "r"	+.368	+.179	+.417	+.677	+.539
P. E. of "r"	±.238	±.266	±.227	±.149	±.195
3 x P. E. of "r"	.714	.798	.681	.447	.585

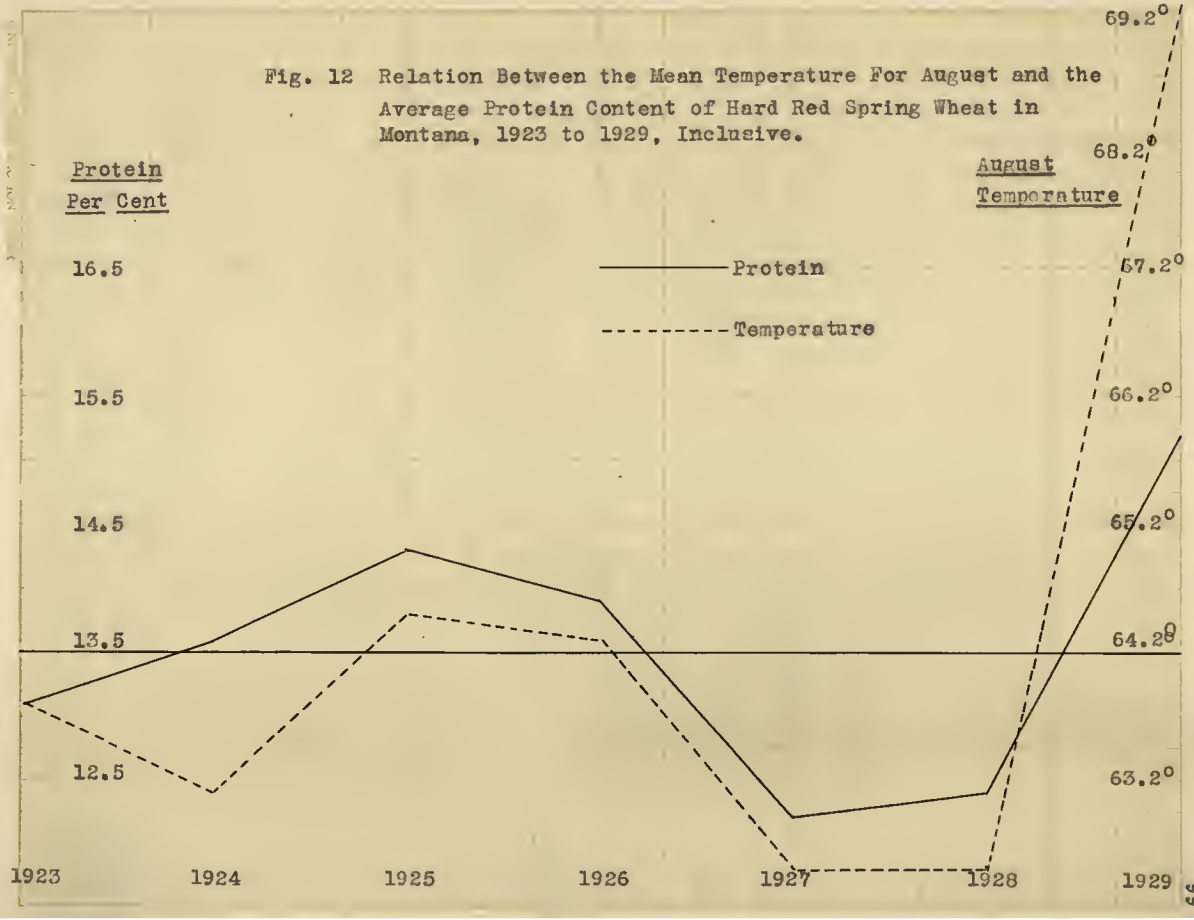
Table XIII. (Continued)

	April	May	June	July	August
Teton County					
Value of "r"	+.389	+.206	+.523	+.615	+.756
P. E. of "r"	±.216	±.244	±.185	±.158	±.109
3 x P. E. of "r"	.648	.732	.555	.474	.327

for August has a high degree of association with the protein content of the hard red spring wheat, the correlation coefficient being +.940 ±.029. July follows with a correlation coefficient of +.512 ±.188. Since under average conditions, much of the spring wheat in Montana is harvested by August 15 to 20, these data suggest the importance of temperature in relation to the protein content during a comparatively short period preceding harvest. Figure 12 shows that except for 1924, the August temperature curve has followed the protein curve rather closely. When the average temperature of the State during August, or the period immediately preceding harvest has been above the mean, the protein content of the spring wheat crop harvested that year has been above average. Conversely, when August temperatures have been below normal, the protein content of the wheat crop also has been below average, with the exception of 1924. In general these results agree with the findings of Mangels (63) who states that in North Dakota, temperatures above normal in June and July increase the protein content of the wheat crop.

While rainfall and temperatures have been considered separately in this paper, it must not be concluded that these important seasonal factors are not connected or inter-related. It is well known that wet seasons often are cooler than

Fig. 12 Relation Between the Mean Temperature For August and the Average Protein Content of Hard Red Spring Wheat in Montana, 1923 to 1929, Inclusive.



normal, as in 1927, while in dry seasons, the temperatures are frequently above the average as in 1929. On the other hand, it may happen that a deficiency of rainfall during the growing season, particularly while the grain is filling, may be accompanied by temperatures lower than normal. Such a condition, namely a dry cool growing season occurred in 1924, in which instance, the deficiency in moisture appeared to more than offset the tendency of the low temperatures to depress the protein content. In other words, the experience of 1924 would indicate that moisture is more important than temperature in causing variations in the protein content of wheat.

Applied To Individual Counties. Four counties, namely, Fallon, Phillips, Hill and Teton were studied and the data obtained were included as a part of Table XIII. With the exception of Fallon County, the most significant correlations are those between the protein content and the mean temperatures for July and August. Fallon County is in the extreme eastern part of Montana where the bulk of the spring wheat is harvested during July, hence it is not surprising that the mean temperature for June is more significant than that of August.

Applied To An Individual Farm. Correlations have been calculated between the mean monthly temperature during the

growing season and the protein content of durum wheat grown in the MC-C and D and MC-A plots in the dry land tillage experiments at the Northern Montana Branch Station, and are presented in Table XIV.

It has already been suggested that correlations based on results obtained from single plots during a short period of years are of doubtful value, yet they are submitted because of their connection with the problem under consideration. The correlations between mean monthly temperatures and protein content of wheat produced under the two tillage methods do not agree and furthermore appear to be somewhat less significant than those calculated for rainfall, shown in Table XI. The temperature correlations suggest that when applied to an individual farm, other factors may tend to mask or offset the possible effects of temperature on the protein content of the wheat crop.

Summary Of Rainfall And Temperature As Seasonal Factors Influencing The Protein Content Of Spring Wheat In Montana. During the seven years, 1923 to 1929, inclusive, the average protein content of Montana-grown hard red spring wheat has varied from a minimum of 12.21 per cent in 1927 to a maximum of 15.22 per cent in 1929, a range of 3.01 per cent that may be attributed to the influence of seasonal factors.

Table XIV: Degree Of Correlation Between The Mean Monthly Temperature During the Growing Season And The Average Protein Content of Durum Wheat on Fallow And on Continuous Cropping at the Northern Montana Branch Station - 1925 to 1929, Inclusive.

	April	May	June	July	August
Alternate Wheat and Fallow					
Value of "r"	+.294	+.035	+.614	+.343	+.636
P. E. of "r"	±.275	±.301	±.187	±.266	±.179
3 x P. E. of "r"	.825	.903	.561	.798	.537
Continuous Cropping					
Value of "r"	+.403	-.208	+.752	+.642	+.525
P. E. of "r"	±.252	±.288	±.131	±.177	±.218
3 x P. E. of "r"	.756	.864	.393	.531	.654

These findings agree in general with those of Lawes and Gilbert (55), Melikov (68), Williams (131), Snyder (96), Jones and Colver (41), Call, Green and Swanson(18) and others in pointing to the fact that season is one of the major factors causing variations in the protein content of wheat.

Of the two seasonal factors, rainfall is more closely correlated with the protein content of a crop of wheat than is temperature, but either rainfall or temperature is capable of causing marked variations or fluctuations, the extent of which will depend in a large measure upon the stage of maturity at which the crop is affected.

Seven years is too short a period on which to base a positive statement regarding the correlation of the protein content of the wheat crop and the character of the season. However, the evidence which has been accumulated during this period indicates that it is reasonable to expect a wheat crop to contain more than the average percentage of protein when hot,dry weather prevails for a period of four to eight weeks preceding harvest, and conversely, a lower than normal protein content may be anticipated when the precipitation during this pre-harvest period is considerably above normal accompanied by relatively cool temperatures.

The seasonal conditions which tend to increase the protein content usually are not favorable to the production

of high yields of grain, as is shown by Figure 13. For the State as a whole, the yield of spring wheat and protein content show a significant negative correlation, -.937 ±.031, during the years 1923 to 1929, inclusive. In other words, there is a marked tendency for the protein content of Montana-grown hard red spring wheat to vary inversely as the yield. While seasonal factors such as rainfall and temperature may be responsible for causing low yields, they operate at the same time to increase the protein content. Therefore, in seasons when there is a shortage of high protein wheat and relatively large premiums are paid, the advantage of an increased protein content may partially offset the disadvantage of a low acre yield.

Influence Of Method Of Tillage Or Seed-bed Preparation On The Protein Content

Nitrogen is considered as one of the most important elements of plant food. The organic matter of the soil contains a large percentage of nitrogen but not until this organic matter is thoroughly decomposed does the nitrogen become available to growing crops. This decomposition process in which certain bacteria play an essential part is termed nitrification and the compounds which contain the available nitrogen are called nitrates.

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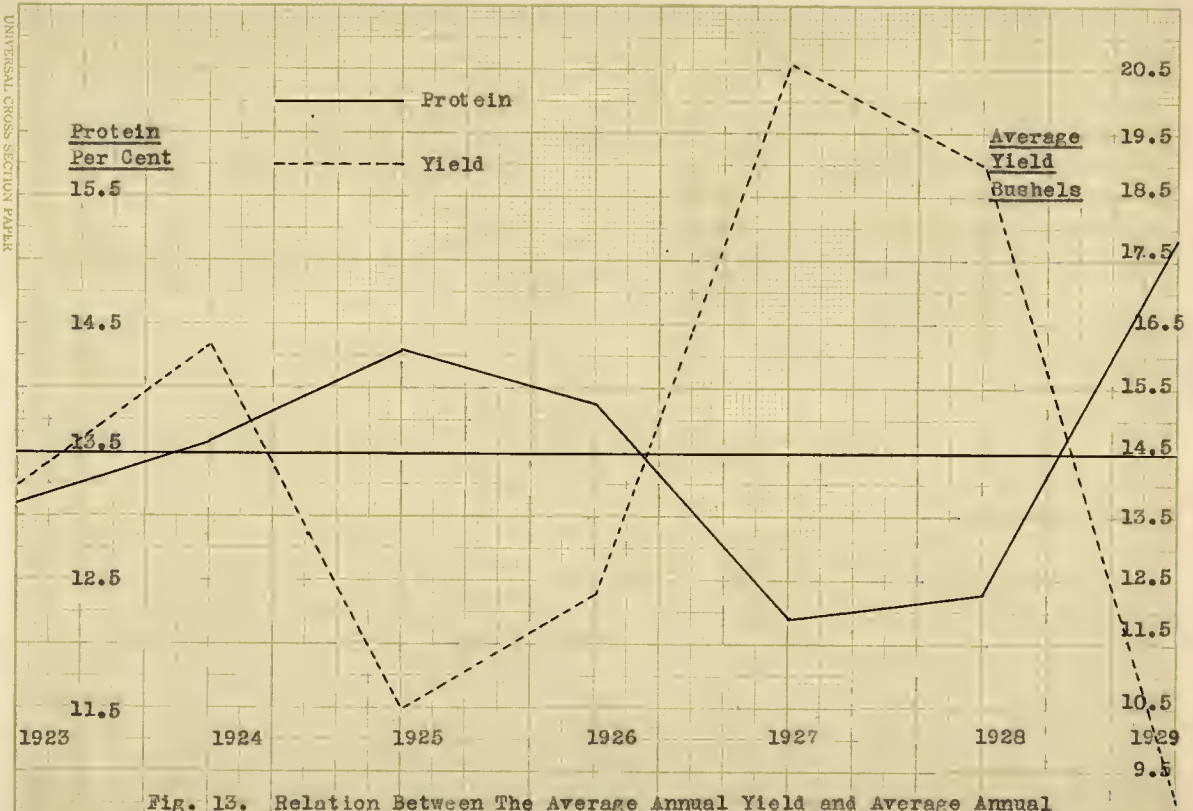

Fig. 13. Relation Between The Average Annual Yield and Average Annual Protein Content Of Hard Red Spring Wheat In Montana, 1923 to 1929, Inclusive.

It has been known for many years that available nitrogen plays an important part in the growth and development of plants. Concerning wheat, Swanson (110) states that the production of grain with a high protein content is possible only if there is present in the soil, an adequate supply of available nitrogen. Investigators working in the leading wheat producing sections of the United States have furnished adequate proof of the fact that tillage operations in the preparation of the seed-bed for wheat have a marked influence upon the conservation of moisture and the accumulation of available nitrogen and consequently upon the yield and protein content of the crop. Sewell and Call (86) report that "the greatest amount of nitrates in the soil at seeding time (for winter wheat) is found in those plots receiving some kind of early summer tillage". According to these investigators, time of preparation was more important than the method used, in so far as the accumulation of nitrate was concerned. Sewell and Swanson (87) concluded from their work with winter wheat in Kansas that "the per cent of protein in wheat is materially affected by the quantity of nitrates in the soil". and further that "the tillage treatments which produce the largest quantity of nitrates in the soil, not only produced the largest yield

of wheat and the highest per cent of protein, but the flour from this wheat was also of superior quality as measured by loaf volume and texture of the bread.

Burke (15) reports that "the purpose of fallowing land in Montana is to conserve moisture, keep the land free from weeds, and liberate plant foods, especially nitrogen, which in the majority of cases is the limiting factor, so far as plant foods are concerned, in crop production". However, he makes it perfectly plain that "moisture is absolutely necessary and is often the limiting factor in crop yields", and explains also that moisture conserved by clean summer tillage not only improves the physical condition of the soil but accelerates the action of bacteria and thus hastens the rate at which nitrogen is made available. The advantages of fallow over continuous cropping as related to moisture conservation, amount of nitrate nitrogen and the yield and protein content of wheat as determined by Professor Burke over a period of seven years are shown by Table XV.

The results of experiments conducted cooperatively by the Montana Agricultural Experiment Station and the United States Department of Agriculture at three branch stations, namely, Northern Montana Branch Station at Havre, the Judith Basin Branch Station at Moccasin and the Huntley Branch

Table XV: Advantages Of Fallow Over Continuous Cropping As Related to Moisture Conservation, Amount of Nitrate Nitrogen and the Yield and Protein Content of Wheat - Fort Ellis Station Near Bozeman, Montana, 1911 to 1917, Inclusive.

	Spring Wheat On		Winter Wheat On	
	Fallow	Cont. Crop.	Fallow	Cont. Crop.
Moisture - First three feet of soil	17.89%	16.87%	17.50%	17.00%
Nitrate nitrogen - p. p. m.	5.98	2.34	5.21	2.73
Yield per acre	34.5 bu.	21.5 bu.	42.7 bu.	25.6 bu.
Protein content of wheat	15.96%	11.63%	14.13%	11.88%

Station at Huntley have been examined to determine to what extent they support the observations of many Montana wheat growers that spring wheat grown on clean fallow not only yields better but often contains a higher percentage of protein than if the crop immediately follows wheat or other small grains.

Methods Of Seed-Bed Preparation. The continuous cropping experiments with spring wheat at these branch stations provide an opportunity to study the influence of five methods of seed-bed preparation upon the protein content, including (a) ordinary spring plowing; (b) ordinary fall plowing; (c) alternate crop and fallow; (d) subsoiling; and (e) listing. Table XVI gives the protein content for each of these tillage treatments for a period of five years, 1925 to 1929, inclusive at the Northern Montana Branch Station. It will be observed that wheat produced on plots C and D, alternate crop and fallow, has the maximum protein content, an average of 15.75 per cent for the five years. This is a distinct advantage over any other method. Wheat grown on a seed-bed prepared by plowing and subsoiling ranked second in average protein content, but is given no further consideration due to the fact that this method of preparation has proven impractical under Northern Great Plains

Table XVI: Protein Content* Of Spring Wheat Grown Under Different Methods Of Tillage Or Seed-Bed Preparation In The Continuous Cropping Experiments At The Northern Montana Branch Station, 1925 to 1929.

Plot	Tillage	1925	1926	1927	1928	1929	5 yr. ave.
		%	%	%	%	%	%
A	Spring Plowed	12.89	14.79	12.72	11.39	12.91	12.94
B	Fall Plowed	13.91	14.94	12.84	12.77	13.17	13.32
C & D	Alt. Crop and Fallow	17.46	16.02	14.02	14.39	16.86	15.75
E	Subsoiled	16.12	15.14	12.94	12.33	17.46	14.80
F	Listed	13.18	15.26	11.80	11.54	12.67	12.89

* Protein tests made by the Chemistry Department of the Montana Experiment Station - N x 5.7 expressed on basis of 13.5 per cent moisture.

conditions. Between spring plowing, fall plowing and listing, the experience of this five-year period shows no significant differences so far as the average protein content is concorned. In comparing fallow with spring plowing, there is an advantage of 2.81 per cent protein in favor of the former for the five-year period, the difference in individual seasons ranging from 1.23 per cent in 1926 to 4.57 per cent in 1925.

It is not safe; however, to conclude from the data given in Table XVI that fallow is always so effective in increasing the protein content of wheat. It will be of interest to examine the data from the same series of tillage treatments as conducted at the Judith Basin Branch Station. On this station, the annual precipitation averages 4 to 5 inches higher than at Havre, but soil conditions are somewhat less favorable to the conservation of moisture. The shallow surface soil is underlaid by a subsoil consisting largely of gravel cemented together with a calcareous material. Table XVII. presents the protein data by years together with the averages for the five years, 1925 to 1929, inclusive. While fallow again produced the highest average protein content, the advantage over the other tillage treatments is not so striking as at the Northern Montana Branch Station.

Table XVII: Protein Content* Of Spring Wheat Grown Under Different Methods of Tillage Or Seed-Bed Preparation In The Continuous Cropping Experiments At The Judith Basin Branch Station, 1925 to 1929.

Plot	Tillage	1925	1926	1927	1928	1929	Ave.
		%	%	%	%	%	%
A	Spring Plowed	17.00	16.20	13.80	13.45	17.50	15.59
B	Fall plowed	16.51	16.47	13.18	12.70	17.10	15.19
C & D	Alt. Crop and Fallow	17.10	15.90	12.75	14.80	19.05	15.92
E	Subsoiled	16.07	15.66	12.91	13.80	17.65	15.22
F	Listed	15.28	15.06	12.75	14.40	16.45	14.79

* Protein tests made by the Chemistry Department of the Montana Experiment Station - n x 5.7 expressed on basis of 13.5 per cent moisture.

Because of the fact that summer tillage or clean fallow is the most effective method of storing moisture in the soil in regions of limited rainfall, it is recognized as the best form of insurance against crop failure due to drought. The fact that fallow produces conditions which normally increase the protein content of wheat over that grown by other tillage methods is an additional reason for the growing popularity of this method of seed-bed preparation among Montana wheat growers.

Because of the importance of fallow or clean summer tillage in this State, experiments have been conducted to determine the best methods of fallowing, also the most practical methods of preparing fallow land for the planting of spring wheat. These experiments have afforded an opportunity to study the influence of variations in these practices on the protein content.

Methods Of Fallowing. During a period of four years, 1926 to 1929, inclusive, an experiment involving four methods of fallowing was conducted at the Northern Montana Branch Station at Havre. Three plots were plowed for fallowing, in the fall, with subsequent treatment as follows: (a) left rough; (b) worked down; and (c) worked down and packed. The second method involved four plots plowed for fallowing

in May, with treatment previous to plowing as follows: (a) no treatment before plowing; (b) stubble double-disked in both the fall and spring before plowing; (c) stubble double-disked in the fall (d) stubble double-disked in the spring. The third method included four plots plowed for fallowing in July, the treatment before plowing being the same as for the four plots plowed in May. The fourth method required only one plot which was not plowed, the summer tillage being accomplished with a duckfoot weeder after the manner commonly spoken of as "plowless fallow".

The protein data obtained are presented in Table XVIII. Thus far, no outstanding differences in the average protein content of spring wheat produced by the different methods of fallowing are apparent, the range between the maximum and minimum averages being only 0.78 per cent. The July plowed plots show a tendency to produce, wheat with a slightly lower average protein content during this four-year period but the difference is too small to be significant. Judging by the conditions prevailing during the period of this experiment, factors other than the protein content must determine the method of fallow to be used in producing a crop of wheat.

Table XVIII: Protein Content* Of Marquis Wheat Grown On Different Methods of Fallow At The Northern Montana Branch Station At Havre, 1926 to 1929.

Time of Plowing and Cultural Treatment	1926	1927	1928	1929	Average
Fall Plowed					
Left Rough	16.79	13.26	15.10	18.04	15.80
Worked down	17.72	13.10	15.15	18.34	16.08
Worked down, packed	17.33	12.68	15.20	18.12	15.83
May Plowed					
No treatment	16.64	13.23	15.45	18.60	15.98
Stubble DD in fall & spring	16.51	13.33	15.70	18.42	15.99
Stubble DD in fall	16.47	13.72	15.70	18.21	16.03
Stubble DD in spring	16.30	13.55	15.70	18.34	15.97
July Plowed					
No treatment	17.87	12.42	15.10	18.47	15.97
Stubble DD in fall and spring	17.60	11.93	15.55	16.82	15.48
Stubble DD in fall	17.84	12.15	15.60	17.04	15.66
Stubble DD in spring	16.82	12.02	15.30	17.04	15.30
Duckfoot - not plowed	17.16	12.59	15.55	18.25	15.89

* Protein Analyses in 1926 and 1927 made by the Chemistry Department and in 1928 and 1929 by the Montana Grain Inspection Laboratory, Montana Experiment Station - N x 5.7 on basis 13.5 per cent moisture.

Methods Of Preparing Fallowed Land Before Seeding

During the five-year period, 1925 to 1929, inclusive an experiment has been conducted at the Northern Montana Branch Station at Havre to determine the most practical methods of preparing summer-fallowed land for the seeding of spring wheat. Land plowed for fallow in May and kept clean with the usual methods of tillage during the summer was handled in four different ways in the spring prior to seeding, as follows: (a) fallow cultivated just before seeding, the latter being done at three dates, approximately April 16, May 5 and May 20, (b) no treatment, wheat being drilled directly on the fallow, approximately April 16, (c) cultivated April 16 and again just before drilling, approximately May 5; and (d) cultivated on April 16, May 5 and again just before seeding, approximately May 20.

The protein data for each treatment are given in Table XIX. While some rather marked differences in the protein content are evident, particularly in the four and five-year averages, it appears that these variations are due primarily to differences in the time of seeding rather than to the method of handling the fallow land in the spring previous to seeding.

Table XIX: Protein Content Of Marquis Wheat Grown On Fallow Handled In Four Different Ways In The Spring Previous To Seeding. Northern Montana Branch Station, Havre, 1925 to 1929.

Date Sown and Method	1925	1926	1927	1928	1929	4 yr. ave.	5 yr. ave.
	%	%	%	%	%	%	%
April 16 - - - A	16.30	14.90	13.01	14.05	16.95	15.55	15.04
April 16 - - - B	15.92	15.60	-	13.20	17.43	15.54	-
May 5 - - - - C	16.91	17.00	13.76	16.15	18.81	17.22	16.53
May 5 - - - - A	18.07	16.30	-	15.94	19.12	17.36	-
May 20 - - - - D	17.16	16.80	13.04	15.20	19.81	17.24	16.40
May 20 - - - - A	16.32	17.00	-	15.74	19.72	17.19	-

A - Fallow cultivated just before drilling.
B.- No treatment, wheat drilled directly on fallow.
C - Cultivated April 16 and again just before drilling.
D - Cultivated April 16, May 5 and again just before drilling.
Note: Dates given are only approximate.

Influence Of Green Manures On The Protein Content Of Spring Wheat

Wherever wheat is grown extensively, the problem of maintaining the supply of organic matter in the soil eventually becomes one of major importance. Soils well supplied with organic matter are, more easily tilled, absorb and retain a larger proportion of the seasonal precipitation and supply a larger quantity of available nitrogen to the growing crop than those from which the organic matter has been largely dopleted. Since organic matter is a source of nitrogen, and available nitrogen has a direct bearing on both the yield and protein content of wheat, it will be of value to know to what extent the growing of green-manures or the application of barn-yard manure in the cropping system may influence the crop, particularly under conditions where moisture is frequently the limiting factor in crop production.

The crop rotation experiments conducted at the Northern Montana Branch Station, cooperatively by the Montana Agricultural Experiment Station and the United States Dopartment of Agriculture afford an opportunity to study the effects of three crops, namely, winter rye, peas and sweet clover used as green manures, in comparison with ordinary fallow,

on the protein content of spring wheat. Two basic crop sequences are involved: (a) one year devoted to green manure or ordinary fallow, followed in order by one year each of spring wheat, corn and oats, and (b) one year devoted to green manure or ordinary fallow, followed in order by one year each of oats, corn and spring wheat. In the first sequence, wheat is the first crop after geen manure or fallow, while in the second, wheat is three years removed from the effects of these treatments.

Table XX presents the average protein content and the average yield of spring wheat for the five-year period, 1925 to 1929, inclusive, arranged to show the influence on the crop planted one year and three years after the various treatments. So far as the average protein content is concerned, there is a rather marked uniformity among the five treatments, regardless of whether wheat is the first or third crop to follow. It will be noted that without exception, wheat produced the first year after the different treatments contained considerably more protein than that which was three years removed from the influence of green manure or fallow. (See Figure 14). When wheat was the first crop to follow, the maximum percentage of protein, 16.72 per cent, was produced by Rotation 72, wheat after manured

Table XX: Average Protein Content And Yield Of Spring Wheat Grown One Year* And Three Years** After A Green Manure Crop Or After Fallow At The Northern Montana Branch Station, 1925 to 1929, Inclusive.

Rot. No.	Time and Treatment	Ave. Protein %	Ave. Yield. Bu.
15	First year after winter rye - G. M.	16.19	21.3
14	Third " " " " " "	14.05	18.4
		+2.14	+2.9
17	First year after peas - G. M.	16.31	17.9
16	Third " " " " "	14.72	20.8
		+1.59	-2.9
32	First year after sweet clover - G. M.	16.64	21.1
31	Third " " " " " "	14.38	18.2
		+2.26	+2.9
18	First year after fallow	15.73	27.5
19	Third " " "	13.55	20.7
		+2.18	+6.8
72	First year after fallow - manured	16.72	28.5
71	Third " " " "	14.82	23.5
		+1.90	+ 5.0

* Rotation consisted of green manure or fallow, followed in order by one year each of wheat, corn and oats.

** Rotation consisted of green manure or fallow followed in order by one year each of oats, corn and wheat.

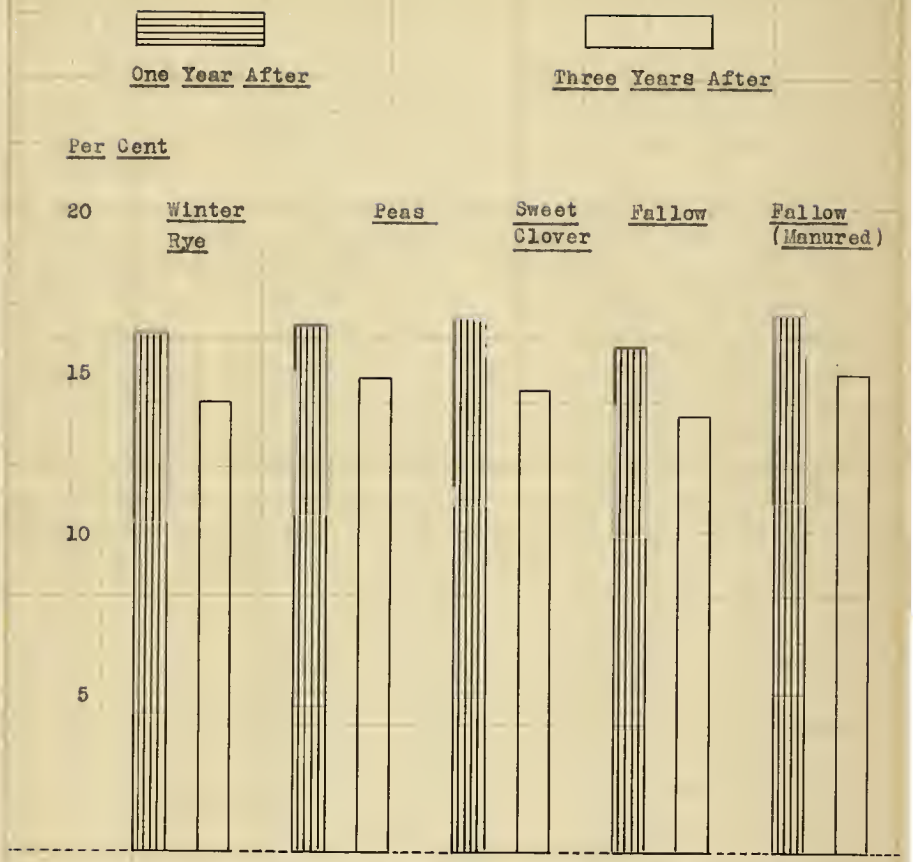

Fig. 14 - Protein Content Of Spring Wheat One Year And Three Years Following Various Green Manures and Ordinary And Manured Fallow At The Northern Montana Branch Station, 1925 to 1929, Inclusive.

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fallow, while the minimum test, 15.73 per cent, came from Rotation 18, wheat following ordinary fallow, a range of 0.99 per cent. Of the three green-manure crops, wheat one year following sweet clover ranked first with an average protein content of 16.64 per cent for the five-year period, an advantage of only 0.33 per cent over that produced one year following peas used as a green-manure. Winter rye ranked third among the green-manures, the wheat following one year after this treatment averaging 16.19 per cent protein. However, the results obtained from the three green-manure crops are not strictly comparable. Since each crop is allowed to grow until the maximum vegetative growth is available to plow under there is of necessity, considerable variation in the average dates of plowing. During the five years, the average dates on which these three crops were plowed under were as follows: winter rye on June 15; sweet clover on June 23, and peas on July 13. The wide difference in the dates on which the green-manure crops have been plowed under introduces a variable which may influence the results quite as much as the crops themselves.

When both the average yield and the protein content are considered, the data now available indicate that for the present at least, moisture is somewhat more of a limiting factor in crop production than is plant food. Therefore,

under the conditions of this experiment, the practice of green manuring can scarcely be considered a practical procedure in the production of spring wheat.

Influence Of Fallow Vs Disked Corn Ground On The Protein Content Of Spring Wheat

In those parts of Montana where corn may be utilized to advantage in the feeding of livestock, there is a tendency to reduce the acreage of summer fallow somewhat and sow a part of the spring wheat on disked corn ground. Farmers frequently have raised the question as to the protein content of wheat raised immediately following corn as compared with that grown after clean fallow.

The crop rotation experiments at the Northern Montana Branch Station provide an opportunity to compare the protein content of spring wheat in five different cropping systems in which wheat is planted on disked corn ground with that in five other sequences in which wheat is preceded either by ordinary fallow or green-manure fallow. Table XXI shows that from the standpoint of both protein content and yield, wheat preceded by a season of clean fallow is distinctly superior to that planted on disked corn land. A similar comparison of cropping systems at the Judith Basin Branch Station where summer tillage is less efficient in the

Table XXI: Average Protein Content Of Spring Wheat Grown On Fallow And On Disked Corn Land At The Northern Montana Branch Station, 1925 to 1929,,Inclusive.

Rotation and Crop Sequence	Protein	Yield
	%	Bu.
Wheat After Fallow		
MC-C&D - Alternate fallow and wheat	16.27	25.3
18 - Corn (S.P.);Oats (D.C.); Fallow; Wheat	16.03	27.5
32 - Corn (S.P.);Oats (D.C.); Sweet Clover (G.M.); Wheat	16.86	21.1
15 - Corn (S.P.);Oats (D.C.); W. Rye (G.M.); Wheat	16.54	21.3
17 - Corn (S.P.);Oats (D.C.); Peas (G.M.); Wheat	16.48	17.9
Average	16.43	22.6
Wheat After Disked Corn		
49 - Corn (F.P.); Wheat (D.C.)	15.21	19.2
19 - Fallow;Oats; Corn (S.P.); Wheat (D.C.)	13.57	20.7
31 - Sweet clover (G.M.); Oats; Corn (S.P.); Wheat (D.C.)	15.31	18.2
14 - W. Rye (G.M.); Oats; Corn (S.P.); Wheat (D.C.)	14.32	18.4
16 - Peas (G.M.); Oats; Corn (S.P.); Wheat (D.C.)	14.93	20.8
Average	14.67	19.4
Average advantage in favor of wheat after fallow	1.76	3.2

storage of moisture in the soil, reveals the fact that wheat after corn yielded fully as well as wheat after fallow during the same five-year period, but wheat after fallow had the advantage in protein content by 1.13 per cent.

Under the conditions which have prevailed at these two branch stations during the five years, 1925 to 1929, inclusive, there is strong evidence that summer fallowed land will produce wheat with a higher protein content than that grown on disked corn ground.

Influence Of The Class Of Wheat On The Protein Content

Several investigators, including Thomas (119, 120), Shollenberger and Clark (84), Thatcher (112), Stewart and Greaves (104), Ladd (50,51), Bailey (5,7), Stephens and Hyslop (102) and Kiesselbach (45) have noted differences in the protein content of wheat of the various classes when grown under comparable conditions. Among the classes of wheat in which Montana is interested, it has been found that the protein content of hard red spring wheat exceeds that of the hard red winter class, while durum wheat contains a higher percentage of protein than either of the hard red wheats.

Hard Red Spring Vs Hard Red Winter Wheat In Montana. During the three-year period, 1927 to 1929, inclusive, data

were obtained on the protein content of hard red winter wheat grown in Montana. The data for each season are arranged by counties in Figures 15 to 17. Table XXII compares the average protein content of hard red winter wheat with that of hard red spring wheat for each of the three years. It will be observed that during this period, spring wheat has averaged 1.07 per cent higher in protein than winter wheat. For the individual seasons, the differences were as follows: in 1927, -1.24 per cent; in 1928, -0.24 per cent; and in 1929, -1.74 per cent, each year the difference favoring hard red spring wheat. In general, these findings agree with the data reported by the investigators cited above.

Durum Wheat vs Hard Red Spring Wheat In Montana. Investigators in the United States Department of Agriculture (119, 120, 84) also in North Dakota (48, 49, 52, 65) report data showing that durum wheat contains a higher percentage of protein than hard red spring wheat.

Morgan and Bell (71) report the protein content of several varieties of spring wheat grown at the Northern Montana Branch Station during a period of seven years, 1917 to 1924 (1923 omitted). During this seven-year period, Marquis, a typical variety of hard red spring wheat has

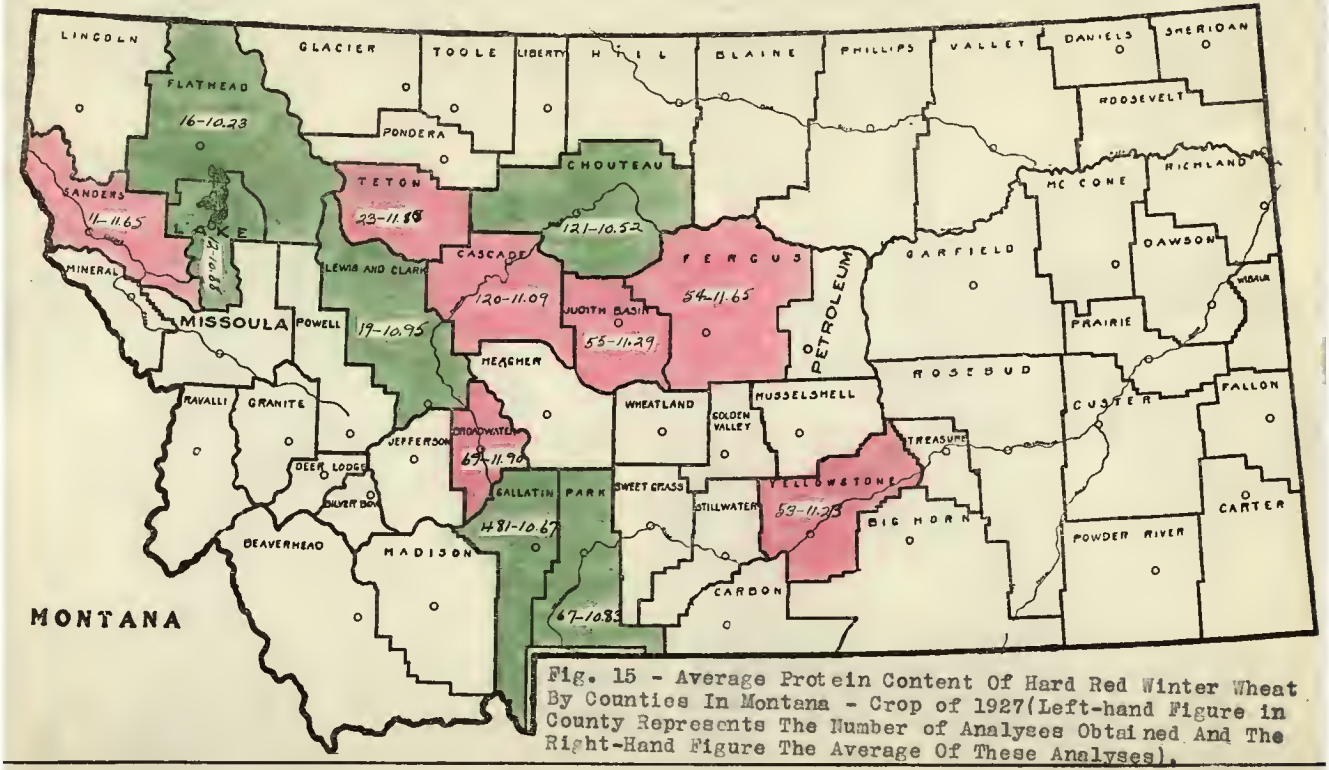

Fig. 15 - Average Protein Content Of Hard Red Winter Wheat By Counties In Montana - Crop of 1927(Left-hand Figure in County Represents The Number of Analyses Obtained And The Right-Hand Figure The Average Of These Analyses).

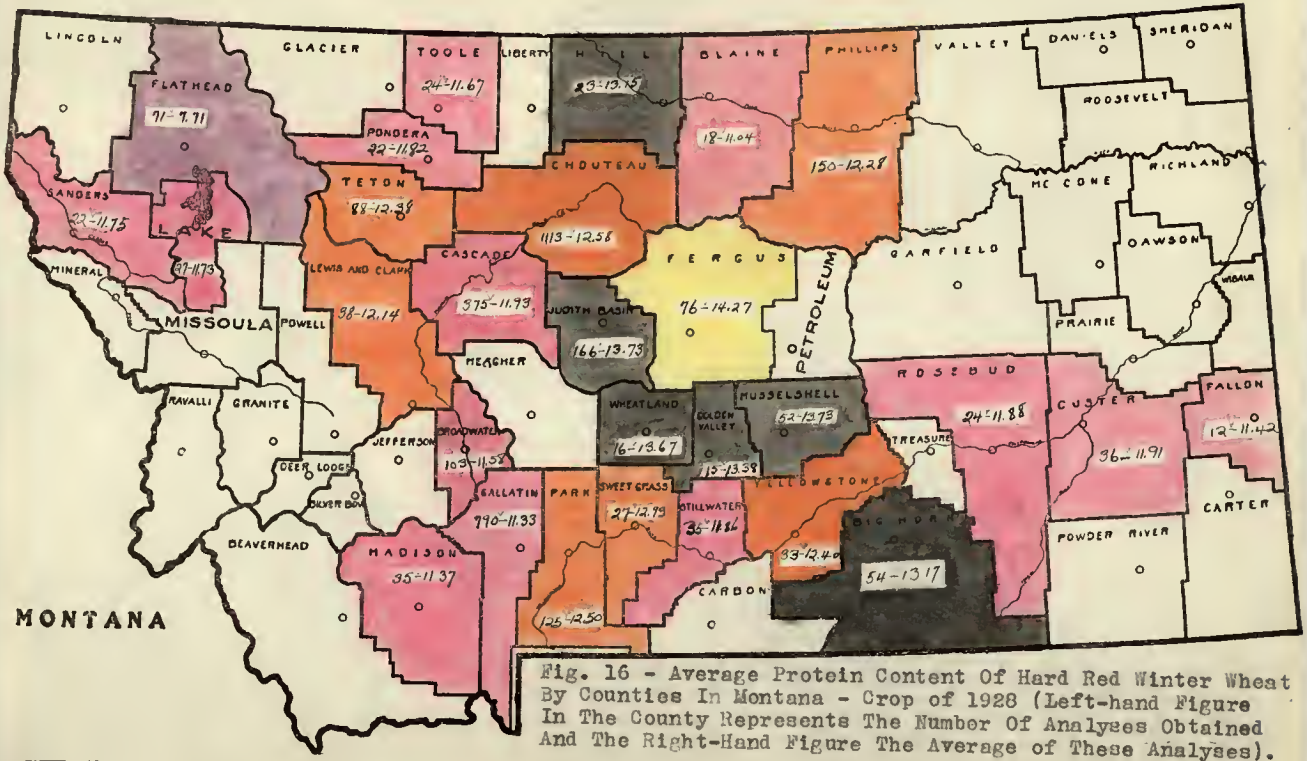

Fig. 16 - Average Protein Content Of Hard Red Winter Wheat By Counties In Montana - Crop of 1928 (Left-hand Figure In The County Represents The Number Of Analyses Obtained And The Right-Hand Figure The Average of These Analyses).

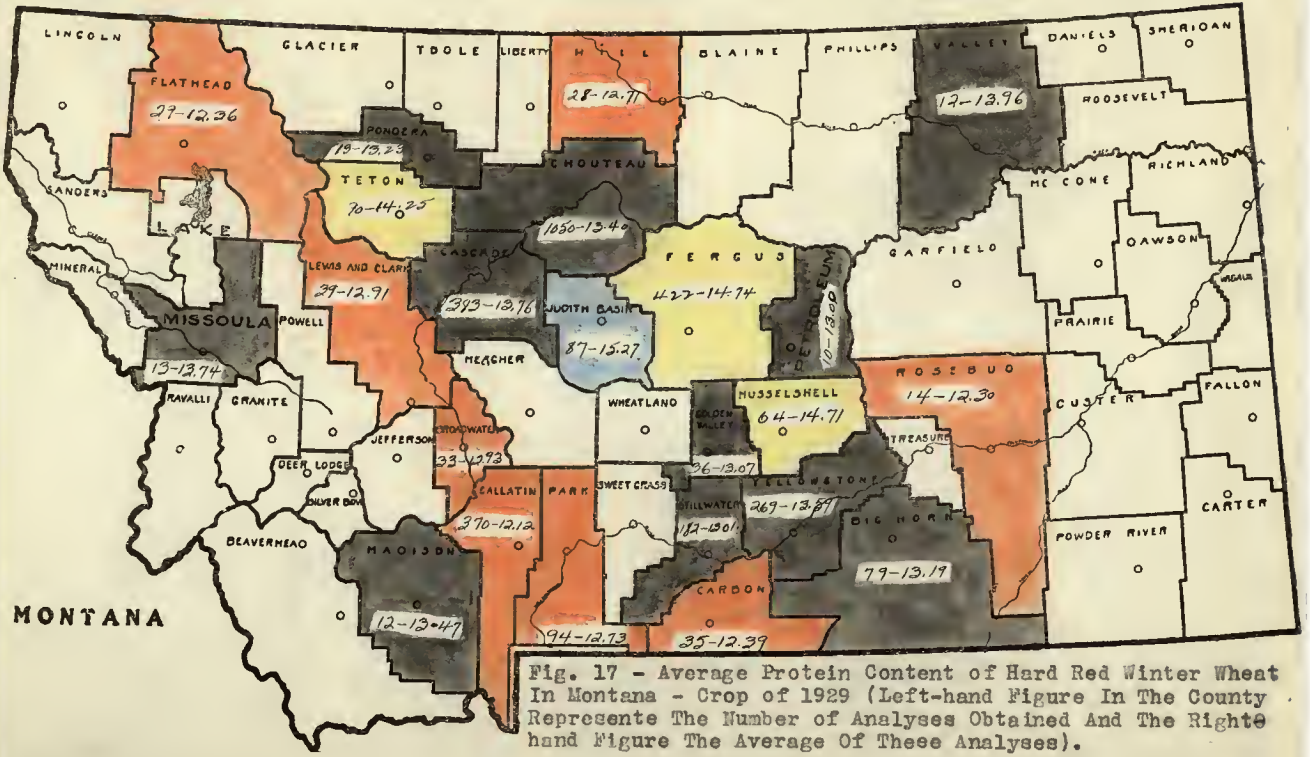

Fig. 17 - Average Protein Content of Hard Red Winter Wheat In Montana - Crop of 1929 (Left-hand Figure In The County Represente The Number of Analyses Obtained And The Righte hand Figure The Average Of These Analyses).

Table XXII: Average Protein Content of Hard Red Winter Wheat and Hard Red Spring Wheat in Montana, 1927 to 1929, Inclusive.

Year	Hard Red Spring Wheat Analyses	Ave. Prot.Cont.	Hard Red Winter Wheat Analyses	Ave. Prot.Cont.
1927	15826	12.21%	1176	10.97%
1928	31071	12.39%	3640	12.15%
1929	11337	15.22%	3422	13.48%
Ave.* 3 yrs.		13.27%	Ave.* 3 yrs.	12.20%

* Arithmetical average

averaged 16.67 per cent protein, while Kubanka and Pelissa (durum varieties) averaged 17.10 and 17.50 per cent respectively during the same years.

While it is apparent that durum wheats contain a higher percentage of protein than does hard red spring wheat, the former are not necessarily superior owing to the poor quality of the gluten for bread making purposes.

Influence Of Variety On The Protein Content Of Spring Wheat

In proposing a new variety of wheat to grow in any locality, the yield of grain is only one of several important factors that are taken into consideration. Not only must a variety be sufficiently well adapted to local environmental conditions to produce maximum yields of grain

but this grain must be of a quality which will return a superior product in the hands of the miller and the baker. Important among the qualities in which these industries are interested when a new variety of wheat is put on the market is the percentage of protein.

The spring wheat variety tests conducted by the Agronomy Department of the Montana Agricultural Experiment Station furnish information relative to the extent to which varieties of spring wheat differ in regard to their protein content. In order to save space, only a few of the high yielding varieties, some of which have attracted the attention of the public will be considered. Marquis is chosen as a standard with which the other varieties are compared because it is the most common variety of hard red spring wheat in the State.

Table XXIII shows Marquis compared with three varieties namely, Federation, Supreme and Kitchener as to yield and protein content, when grown in triplicate one-fortieth acre plots during a period of seven years, 1923 to 1929, inclusive. On the basis of yield alone, there is ample justification for the interest shown by farmers in such varieties as Federation and Supreme. However, when the quality of the grain, as indicated by the percentage of

Table XXIII: Yield and Protein Content of Certain Varieties of Spring Wheat Grown on Triplicate One-fortieth Acre Plots at Bozeman During Seven Years, 1923 to 1929, Inclusive.

	1923	1924	1925	1926	1927	1928	1929	Ave.
Yield - Bushels								
Federation	52.3	52.3	69.7	37.3	71.6	72.7	76.9	61.8
Supreme	62.3	38.9	62.3	36.1	69.3	70.1	67.6	58.1
Kitchener	43.6	41.5	58.9	43.7	65.9	66.8	69.1	55.6
Marquis	57.2	36.5	47.4	42.1	68.3	69.2	64.4	55.0
Protein*- Percentage								
Federation	11.29	15.77	9.99	10.50	10.54	7.83	8.55	10.64
Supreme	14.28	15.45	11.48	11.41	12.73	10.02	10.05	12.20
Kitchener	15.59	17.16	12.77	12.85	12.36	9.95	10.75	13.06
Marquis	12.69	16.53	12.97	14.76	12.22	11.12	11.95	13.18

* N x 5.7 - basis 13.5 per cent moisture.

protein is considered, both of these varieties are at a serious disadvantage when compared with Marquis.

Considering the prominence of protein as a factor in the marketing of hard red wheats, and the variation in the protein content of different varieties when grown under comparable conditions, the following suggestions seem pertinent: (a) protein content of the parent material and progeny should be given considerable attention in any program of wheat breeding designed to produce better varieties for this State; (b) in areas adapted to the production of hard red spring wheat of high quality and in which production is largely confined to one variety such as Marquis, the Agricultural Experiment Station is justified in withholding from distribution any variety which does not at least equal the standard variety in protein content. The experience with Supreme in cooperative tests in Montana during the past few years has shown rather definitely that the average wheat grower is not at all interested in using a variety which has a lower average protein content than Marquis, in spite of the fact that Supreme has outyielded Marquis by a significant margin.

SUMMARY

The protein content of the common bread wheats is

generally regarded as a reasonably reliable basis from which to estimate their milling and baking value.

The protein content of wheat varies considerably, being influenced by many factors, important among which are (a) environment; (b) season, (c) tillage methods; (d) sequence of crops; (e) manuring practices; (f) class of wheat; and (g) variety.

Eighty-two and one-half per cent of the car-load shipments of Montana-grown hard red spring wheat tested at Minneapolis during the months of heavy market receipts, contained 12.00 per cent or more of protein, during a period of seven years, 1923 to 1929, inclusive. The percentages of cars testing 12.00 per cent protein or more, varied from 54.8 per cent in 1927 to 96.3 per cent in 1925.

Montana wheat growers are interested in high protein wheat primarily because the State is located within an area which is favorable to the production of high quality milling wheat, and also because the premium which mill buyers pay for this extra quality partially offsets the freight handicap to which Montana is subject in competing with States nearer the terminal markets.

The size of the premium paid for extra protein content is subject to extreme variation, being influence to a large extent by the amount of high protein wheat available. When

there is a scarcity of high protein wheat in the United States, premiums are likely to be higher than in seasons when a large volume of such wheat is being marketed.

The cause of the variation in the protein content of wheat has been the subject of extensive investigations for over fifty years.

Difference of opinion in regard to the extent to which the protein content of wheat is influenced by various factors may be explained by the wide range of conditions under which the research work on this problem has been done and by the fact that several of the important factors which influence the protein content of wheat are inter-acting, hence conclusions cannot be drawn concerning one factor without at the same time considering the influence of other related factors.

The average protein content of Marquis spring wheat grown in ten different States from seed supplied each year from Bozeman, varied from 10.72 per cent to 15.79 per cent, during a three-year period, 1923 to 1925, inclusive, a range of 5.07 per cent due to the influence of environment.

The greatest range between States during this three-year period, occurred in 1924, when wheat produced at Moro, Oregon, averaged 18.12 per cent protein, while that grown at Pullman, Washington contained only 10.07 per cent, a

range of 8.05 per cent due to the influence of environmental factors on the crop of a single season.

The average protein content of hard red spring wheat grown in thirty-eight counties of Montana during a five-year period, 1925 to 1929, inclusive, varied from a minimum of 12.25 per cent in Flathead County to a maximum of 15.09 per cent in Musselshell County, a range of 2.84 per cent due to the influence of environment or location within the State.

The greatest range between counties during this five-year period, occurred in 1926, when the wheat in Musselshell County averaged 16.79 per cent protein, while that from Broadwater County averaged 12.17 per cent, a range of 4.62 per cent due to the influence of environmental factors on the spring wheat of Montana in a single season.

Wheat grown in adjoining fields on any one farm may differ widely in protein content in any single season, due to differences in tillage and methods of cropping. At the Northern Montana Branch Station, the average difference between the protein content of spring wheat produced on fallow and that grown on adjoining land spring plowed and continuously cropped was 2.81 per cent during the five years, 1925 to 1929, inclusive. The greatest spread between these two treatments in any one season was 4.57 per cent in 1925.

High or low protein areas cannot be outlined or designated except in a rather general way because of the wide fluctuations due to the influence of season.

Montana-grown hard red spring wheat has averaged 13.53 per cent protein during the seven years, 1923 to 1929, inclusive.

The annual average protein content of hard red spring wheat in Montana has varied from 12.21 per cent in 1927 to 15.22 per cent in 1929, a range of 3.01 per cent due to the influence of seasonal conditions.

There is a distinct tendency for the protein content of hard red spring wheat in Montana to vary inversely as the total or combined rainfall during July and August; indicated by a correlation coefficient of $-.949 \pm .025$.

There are significant negative correlations also between the average protein content of Montana-grown hard red spring wheat and (a) the total rainfall, April to August, inclusive, (b) the rainfall during July and (c) the rainfall during August.

Correlations between protein content and rainfall which may apply to the State as a whole are not necessarily applicable to a more restricted area, as for example, a single county.

In each of four separate counties studied, there is a significant negetive correlation between the average protein content of the spring wheat and the total rainfall, April to August, inclusive, and with the exception of Fallon County, the same is true for the combined rainfall of July and August.

There has been a significant negative correlation between the average protein content of spring wheat grown both on fallow and on spring plowed continuously cropped land and (a) the July rainfall; and (b) the combined rainfall for July and August, at the Northern Montana Branch Station during the five years, 1925 to 1929, inclusive.

Considering the State as a whole, the coefficient of correlation between the average protein content of hard red spring wheat and the mean temperature for August was +.940 ±.029, while that for July was +.512 ±.188 during the seven years, 1923 to 1929, inclusive. Since much of the spring wheat in Montana is harvested by August 15 to 20, such a correlation suggests that the importance of temperature as a factor in influencing the protein content of that crop is confined largely to a comparatively short period preceding harvest.

Moisture and temperature are inter-related factors as far as their influence on the protein content of spring

wheat is concerned. Seasons in which the moisture supply is above normal are usually cooler than average and produce wheat with a lower than average protein content. Conversely, years in which the rainfall is below normal are usually warmer than the average and result in a crop of spring wheat which contains more than the average percentage of protein.

The only exception to the general observations stated above, during the seven years, 1923 to 1929, inclusive, occurred in 1924. A deficiency of rainfall from April to August, inclusive, was accompanied by temperatures lower than normal, producing a dry, cool, growing season. Since the spring wheat of 1924 averaged slightly above normal in protein content, it would appear that moisture has more influence than temperature in causing variations in the protein content.

Of the two seasonal factors, rainfall is more closely correlated with the protein content of a crop of wheat than is temperature, but either is capable of causing marked variations, the extent of which will depend in a large measure upon the stage of growth at which the crop is affected.

The seasonal conditions which tend to increase the protein content of spring wheat usually are not favorable to

the production of high yields. For the State as a whole, during the period 1923 to 1929, inclusive, the coefficient of correlation between the protein content of spring wheat and the yield is -.937 ±.031, or in other words, there is a strong tendency for the protein content of spring wheat to vary inversely as the yield.

Nitrogen is one of the important constituents of protein. It is a generally accepted fact that all of the nitrogen used by the wheat plant is obtained from the soil and that the plant can absorb only nitrogen which is soluble or readily available.

Available nitrogen is a product of the decay of organic matter in the soil through bacterial action.

Bacterial action resulting in the decay of organic matter and the liberation of plantfood in the soil is accelerated by thorough tillage methods and seed-bed preparation.

Spring wheat on fallow has contained a higher average percentage of protein than that produced by any other method of tillage at both the Northern Montana and Judith Basin Branch Stations, during the five years, 1925 to 1929, inclusive.

At the Northern Montana Branch Station, spring wheat on

fallow has averaged from 1.23 to 4.57 per cent higher in protein content than that grown on spring plowed continuously cropped land, during the five years, 1925 to 1929, inclusive.

There is evidence that the effectiveness of fallow in increasing the protein content of a crop of spring wheat depends to a certain extent upon the efficiency of fallow in conserving the seasonal precipitation.

Factors other than the protein content must determine the method of fallow to be used in preparation for spring wheat, judging from results obtained at the Northern Montana Branch Station during the four years, 1926 to 1929, inclusive.

In four-year crop sequences, spring wheat produced the first year after green manuring with winter rye, sweet clover or peas, or the first year after ordinary or manured fallow contains a considerably higher percentage of protein than when the wheat crop is three years removed from these treatments.

Green manuring does not appear to have a distinct advantage over ordinary fallow as a means of increasing the protein content of spring wheat, based on the results of five years work at the Northern Montana Branch Station.

Clean fallow is more effective than disked corn ground in increasing the protein content of spring wheat.

Montana-grown hard red spring wheat has averaged 13.27 per cent protein during the three years, 1927 to 1929, inclusive, while hard red winter wheat from this State has averaged 12.20 per cent protein during the same period.

Adapted varieties of durum wheat normally contain a slightly higher percentage of protein than Marquis spring wheat.

Varieties of spring wheat may differ materially in protein content, hence this factor should be given important consideration in wheat breeding programs.

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The Chemistry Department and the Montana Grain Inspection Laboratory of the Montana Agricultural Experiment Station made the protein analyses in connection with the tillage, rotation and variety experiments conducted at the main and branch stations.

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